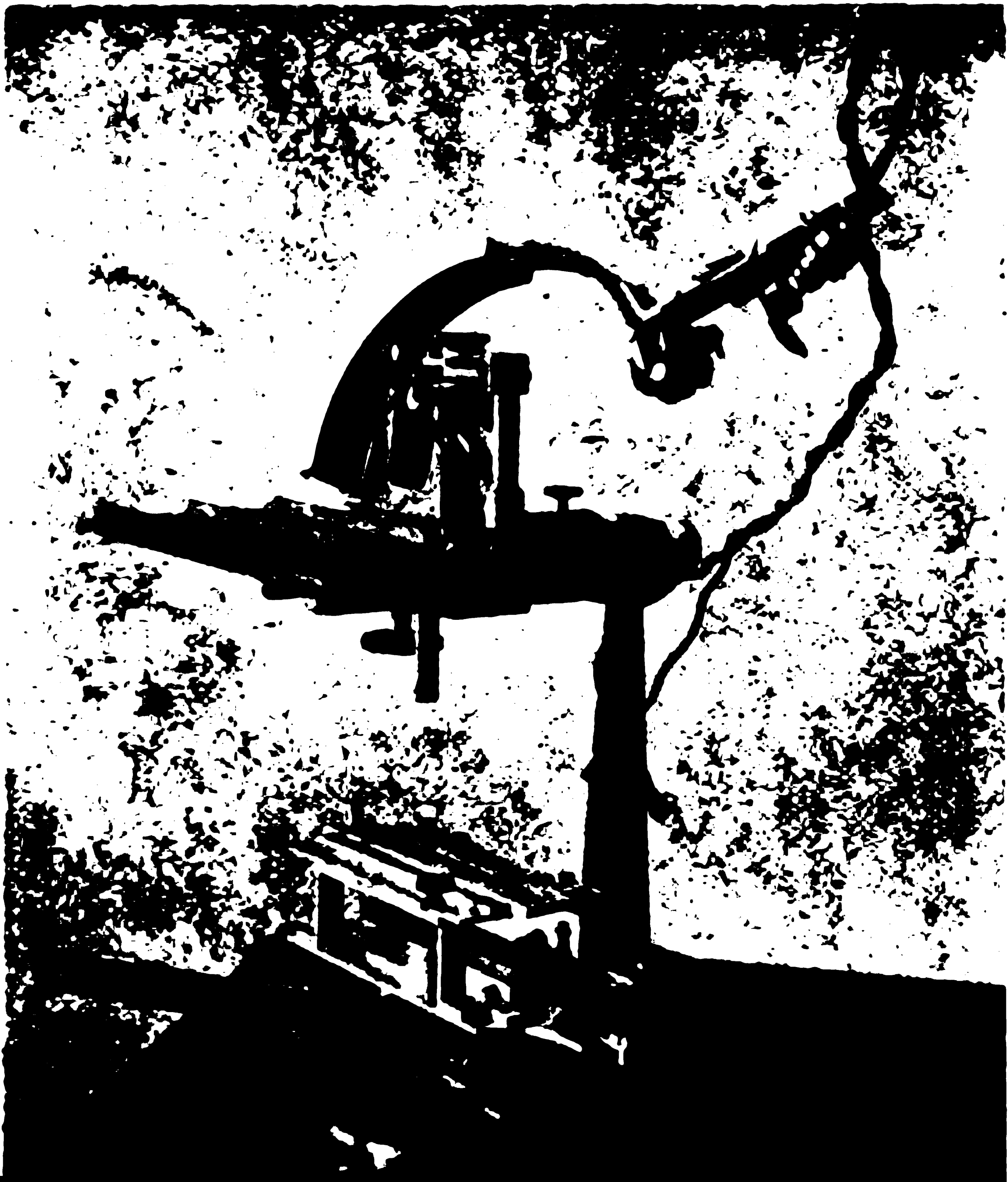

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THE
ASTROPHYSICAL JOURNAL

AN INTERNATIONAL REVIEW OF SPECTROSCOPY
AND ASTRONOMICAL PHYSICS

VOLUME XXXVIII | JULY 1913 | NUMBER 1

STELLAR PARALLAXES FROM PHOTOGRAPHS MADE WITH THE 40-INCH REFRACTOR OF THE YERKES OBSERVATORY

BY FREDERICK SLOCUM AND S. A. MITCHELL

In the *Astrophysical Journal*, Vols. **32**, **33**, and **34**, Professor Schlesinger has published a series of articles on parallax determinations with the 40-inch refractor, and in those articles may be found full descriptions of the apparatus and the methods used in the present investigation.

In but a few respects have we departed from his practice. All of our plates have been taken through a yellow color-filter placed in the plate-holder immediately in front of the photographic plate. For the effects of this procedure see "The Function of a Color-Filter and 'Isochromatic' Plate in Astronomical Photography," by R. J. Wallace, *Astrophysical Journal*, **27**, 106, 1908, and also "On the Errors in Photographic Positions Caused by Observing through Glass," by Frank Schlesinger, *Publications of the Allegheny Observatory*, Vol. **1**, No. 14, p. 101.

Again we have, in general, put two exposures upon a plate instead of three. This has necessitated a revision of the system of weights—and we have adopted the following table of weights (p. 2).

Professor S. A. Mitchell, of Columbia University, as research assistant professor at the Yerkes Observatory for the year 1912–1913, has assisted in making the observations during the past

year and has measured nearly half of the plates used in the present investigation. Mr. Sullivan, the electrician of the Yerkes Observatory, has, as usual, rendered valuable assistance at the telescope. Miss M. M. Hopkins of Smith College, while research assistant during the summer of 1912, measured and reduced one of the fields. Others have from time to time shared in the observational work. The abbreviations in the column marked "Observers" have the following significance: F=Fox, J=Jordan, M=Mitchell, Sl=Slocum, Su=Sullivan, V=Van Maanen.

TABLE OF WEIGHTS

Number of Exposures	Quality of Images		
	Good	Fair	Poor
1	0.7	0.5	0.3
2	1.0	0.7	0.4
3	1.2	0.9	0.5

Miss Eudora Magill, since June 1912 at Yerkes Observatory, has assisted in practically all of the computations.

In the tables and reductions, unless stated to the contrary, all values are in terms of scale divisions. One division of the scale is $\frac{1}{4}$ mm and equals $2''.66$.

In eleven of the fields the displacement has been measured parallel to the equator, and in three, parallel to the ecliptic. The solution in each case yields the proper motion for 100 days. Where the measurements have been made parallel to the equator, the proper motion has also been given in seconds of time per year.

ϕ Andromedae ($1^h 4^m$, $+46°43'$)

This is a binary system OΣ *515*, with components of 4.9 and 6.5 magnitude. The companion has described an arc of more than 90° and, according to the latest observations, was about $0''.25$ distant. The proper motion of the system according to Boss is $+0^s.0007$, $-0''.007$, but according to Auwers $-0^s.0034$, $-0''.012$. The sign of the latter value for the μ_α agrees with the results obtained from the plates.

The magnitude of the pair is 4.28, so the rotating disk was used

to reduce the brightness. Eight plates were secured as described in Table 1. They were measured by Mr. Slocum.

TABLE 1

PLATES OF ϕ *Andromedae*

No.	Date	Hour Angle	Observers	Quality of Images	Remarks
14	1907 Aug. 17	-1^h5	J, Su, J	Fair	
19	Aug. 24	-0.2	J, Su, J	Good	
21	Aug. 31	-1.0	J, Su, J	Good	
56	1908 Jan. 4	$+0.9$	J, J, J	Good	Telescope east
166	1909 Dec. 19	-0.9	Sl, Sl, Sl	Fair	
174	Dec. 23	-0.3	Sl, Sl, Sl	Good	
279	1910 July 30	-1.2	Su, Sl	Good	
292	Aug. 26	-1.8	Su, Su	Fair	

COMPARISON STARS

No.	Diameter	*X* (longitude)	*Y* (latitude)	Dependence
	mm			
2	0.15	-102.5	$+345.5$	$+0.19$
4	.17	$+376.7$	$+129.7$	$+$ .11
5	.20	-220.7	$+$ 51.8	$+$ .21
6	.40	$+256.3$	$+$ 10.2	$+$ .12
9	.31	-338.9	-156.8	$+$ .22
10	.15	$+$ 29.1	-380.4	$+0.15$
Parallax star	0.24	$-$ 65.26	$+$ 0.93	......

The mean magnitude of the comparison stars is 9.2.

TABLE 2

REDUCTIONS FOR ϕ *Andromedae*

Plate	Solution (m)	Weight (p)	Parallax Factor (P)	Time in Days (t)	Residual (v)	$\sqrt{p}\cdot v$ in Arc
14	-1.410	0.9	$+0.956$	-507	$+0.008$	$+0.''02$
19	1.417	1.2	$+0.909$	-500	$+$ .001	$+$ .00
21	1.427	1.2	$+0.850$	-493	$-$ .009	$-$ .03
56	-1.422	1.2	-0.913	-367	$+$ .002	$+$ .01
166	1.431	0.9	-0.778	$+348$	$+$ .014	$+$ .04
174	1.460	1.2	-0.819	$+352$	$-$ .014	$-$ .04
279	-1.450	1.0	$+1.014$	$+571$	.000	.00
292	-1.449	0.7	$+0.892$	$+598$	$+0.002$	0.00

The normal equations are:

$$\begin{aligned} 8.3c - \quad 3.6310\mu + 1.8310\pi &= -11.8924 \\ +181.8672\mu - 7.1963\pi &= +\ 4.6465 \\ +6.6162\pi &= -\ 2.5946 \end{aligned}$$

from which

$$\begin{aligned} c &= -1.4345 \\ \mu &= -0.0030 = -0\overset{''}{.}008 \\ \pi &= +0.0015 = +0\overset{''}{.}004 \pm 0\overset{''}{.}008 \end{aligned}$$

Probable error corresponding to unit weight, $\pm 0.0072 = \pm 0\overset{''}{.}019$.

48 Cassiopeiae ($1^h 54^m$, $+70°25'$)

This star is a visual binary, discovered by Burnham in 1878. The components are 5.0 and 7.5 magnitude. At the time of discovery the distance was a trifle over $1\overset{''}{.}0$, but since then it has decreased to approximately $0\overset{''}{.}3$ and the position angle has changed about 200°. Ten plates were secured as described in Table 1. They were measured by Mr. Slocum. The rotating disk was used to reduce the brightness of the parallax star.

TABLE 1

PLATES OF *48 Cassiopeiae*

No.	Date			Hour Angle	Observers	Quality of Images
57	1908	Jan.	4	$+1^h0$	J, Su, J	Fair
102	1909	Sept.	4	−0.8	Sl, Su, Sl	Fair
136		Oct.	30	− .9	Su, Sl, Su	Fair
175		Dec.	23	− .2	Sl, Su, Sl	Fair
196	1910	Jan.	9	− .4	Sl, Sl	Fair
286		Aug.	20	− .7	Su, Sl	Fair
470	1911	Aug.	19	−1.4	Su, V	Good
591		Dec.	18	− .4	V, Su	Good
611		Dec.	25	− .6	V, Su	Good
638	1912	Jan.	20	−0.1	Sl, V	Good

COMPARISON STARS

No.	Diameter	*X* (longitude)	*Y* (latitude)	Dependence
	mm			
1	0.21	−171.0	− 72.5	0.155
2	.11	−167.6	+147.8	.13
3	.13	− 77.5	−315.9	.19
4	.15	+100.9	+272.9	.15
5	.14	+107.4	− 78.2	.19
6	.17	+207.8	+ 45.9	0.185
Parallax star	0.29	+ 10.62	− 16.82	.....

The mean magnitude of the comparison stars is approximately 10.5.

TABLE 2

REDUCTIONS FOR *48 Cassiopeiae*

Plate	Solution (m)	Weight (p)	Parallax Factor (P)	Time in Days (t)	Residual (v)	$\sqrt{p}\cdot v$ in Arc
57	−0.273	0.9	−0.667	−719	+0.023	+0.″06
102	.338	.9	+0.988	−110	− .019	− .05
136	.326	.9	+0.396	− 54	− .005	− .01
175	.341	.9	−0.506	− 0	− .018	− .05
196	.320	.7	−0.734	+ 17	+ .003	+ .01
286	.350	.7	+1.010	+240	− .018	− .04
470	.317	1.0	+1.009	+604	+ .029	+ .08
591	.340	1.0	−0.421	+725	+ .010	+ .03
611	.339	1.0	−0.528	+732	+ .011	+ .03
638	−0.372	1.0	−0.843	+758	−0.022	−0.06

The normal equations are:

$$\begin{aligned} 9.0c+22.0420\mu-0.3999\pi&=-2.9872\\ +252.0131\mu-2.4578\pi&=-8.0474\\ +4.9265\pi&=+0.1353 \end{aligned}$$

from which

$$\begin{aligned} c&=-0.3229\\ \mu&=-0.0037=-0.''010\\ \pi&=-0.0006=-0.''002\pm0.''016 \end{aligned}$$

Probable error corresponding to unit weight, $\pm0.0137=\pm0.''036$

20 Persei ($2^h 47^m$, $+37° 56'$)

This star, β *324*, consists of two stars of magnitudes 6.0 and 6.7 whose distance never much exceeds 0."2. According to Burnham, an approximate orbit has been found giving a period of 27.7 years, though "these results are of somewhat doubtful value from uncertainty in the adjustment of the measures as to quadrants." 14" distant from this double *AB* is a star *C* of 10th magnitude which must also be a member of the system. The star is of spectral type F. Thirteen plates of this star were obtained. They were measured by Mr. Mitchell. The reductions were carried out at Columbia University by Miss Magill.

TABLE I

PLATES OF *20 Persei*

No.	Date			Hour Angle	Observers	Quality of Images
20	1907	Aug.	24	-1^h2	J, Su, J	Poor
23		Aug.	31	−1.0	Su, J, Su	Fair
78	1908	Nov.	28	−0.4	F, Su, F	Good
182	1910	Jan.	6	−0.9	Sl, Sl, Sl	Fair
197		Jan.	9	−0.5	Sl, Sl	Good
287		Aug.	20	−0.8	Su, Sl	Fair
295		Aug.	26	−0.9	Su, Su	Fair
302		Sept.	9	−1.1	Su, Su	Good
362	1911	Jan.	21	+0.1	Sl	Poor
472		Aug.	19	−1.0	Sl, Su	Fair
487		Sept.	2	−1.6	Su, Sl	Good
629	1912	Jan.	8	−0.8	V, Sl	Good
649		Feb.	4	+0.1	Sl, Sl	Good

COMPARISON STARS

No.	Diameter	*X* (right ascension)	*Y* (declination)	Dependence
	mm			
4	0.22	−174	+235	+0.222
6	.14	−124	−180	.235
9	.19	+ 3	−144	.208
10	.15	+ 83	+278	.167
11	.22	+212	−189	+0.168
Parallax star	0.22	− 17.8	− 5.3	....

The average magnitude of the comparison stars is 9.3. The rotating disk was used to cut down the light of the parallax star.

TABLE 2

REDUCTIONS FOR *20 Persei*

Plate	Solution (m)	Weight (p)	Parallax Factor (P)	Time in Days (t)	Residual (v)	$\sqrt{p}\cdot v$ in Arc
20........	+0.008	0.5	+0.923	−738	−0.013	−0″02
23........	.014	0.9	+ .885	−731	− .008	− .02
78........	.071	1.2	− .355	−276	+ .015	+ .04
182........	.092	0.9	− .825	+128	+ .008	+ .02
197........	.072	1.0	− .848	+131	− .012	− .03
287........	.094	0.7	+ .942	+354	+ .004	+ .01
295........	.083	0.7	+ .935	+360	− .008	− .02
302........	.108	1.0	+ .809	+374	+ .016	+ .04
362........	.092	0.3	− .914	+508	− .016	− .02
472........	.109	0.7	+ .946	+718	− .004	− .01
487........	.113	1.0	+ .872	+732	− .001	.00
629........	.127	1.0	− .837	+862	− .003	− .01
649........	+0.130	1.0	−0.872	+889	−0.002	0.00

The normal equations are:

$$10.9c+28.999\mu+0.9154\pi=+0.9624$$
$$370.2357\mu-7.6200\pi=+4.4552$$
$$7.5998\pi=-0.0153$$

These yield

$$c=+0.0719$$
$$\mu=+0.0063=+0''017 \qquad =+0''005 \text{ per year}$$
$$\pi=-0.0043=-0''012\pm0''007$$

Probable error corresponding to unit weight $=\pm0.0068=\pm0''018$.

No other determination of this parallax has been published.

9 Camelopardalis (4^h44^m, $+66°10'$)

This is a 4.4-magnitude star with a B-type spectrum. Frost and Adams (*Astrophysical Journal*, **19**, 350, 1904) find it to be a spectroscopic binary with very sharp H and K lines which yield variable radial velocity different from that given by the broad lines. The system has been further investigated by O. J. Lee at the Yerkes Observatory (*Astrophysical Journal*, **37**, 1, 1913). Ten plates of this star were obtained for parallax determinations. They were measured by Mr. Mitchell.

TABLE 1

PLATES OF 9 *Camelopardalis*

No.	Date			Hour Angle	Observers	Quality of Images
36	1907	Oct.	5	-1^h0	J, J	Poor
129	1909	Oct.	16	−0.6	Su, Sl, Su	One good
138		Oct.	30	0.0	Su, Sl, Su	Fair
199	1910	Jan.	9	−1.1	Su, Sl	Good
364	1911	Jan.	21	−0.8	Su, Sl	Fair
491		Sept.	2	−1.6	Sl, Su	Fair
626	1912	Jan.	1	0.0	Su, Sl	Fair
633		Jan.	8	−0.4	Su, Sl	Fair
643		Jan.	20	0.0	Su, Sl	Good
659		Feb.	9	−0.1	Su, Sl	Good

COMPARISON STARS

No.	Diameter	X (right ascension)	Y (declination)	Dependence
	mm			
2	0.13	−193	+ 13	+0.287
3	.14	−124	−115	.272
4	.30	−128	+120	.243
12	.13	+231	+213	.123
13	.30	+214	+195	+0.076
Parallax star	0.17	− 75.5	− 9.7	....

The average magnitude of the comparison stars is 8.9. The sector was used to cut down the brilliancy of the parallax star.

TABLE 2

REDUCTIONS FOR 9 *Camelopardalis*

Plate	Solution (m)	Weight (p)	Parallax Factor (P)	Time in Days (t)	Residual (v)	$\sqrt{p}\cdot v$ in Arc
36	−0.096	0.6	+0.864	−794	+0.008	+0.″02
129	.124	0.7	+ .750	− 52	− .019	− .04
138	.104	0.7	+ .570	− 38	− .001	.00
199	.081	1.0	− .577	+ 33	+ .008	+ .02
364	.098	0.7	− .728	+410	− .010	− .02
491	.100	0.7	+ .999	+634	+ .010	+ .02
626	.096	0.7	− .452	+755	− .003	− .01
633	.080	0.7	− .556	+762	+ .011	+ .03
643	.094	1.0	− .714	+774	− .004	− .01
659	−0.087	1.0	−0.902	+794	0.000	0.00

The normal equations are:

$$\begin{aligned} 7.8c + 28.543\,\mu - 1.2665\pi &= -0.7410 \\ 281.6274\mu - 20.4297\pi &= -2.5741 \\ 4.1544\pi &= +0.0775 \end{aligned}$$

These yield

$$\begin{aligned} c &= -0.0959 \\ \mu &= -0.0003 = -0''.001 \qquad = -0''.001 \text{ per year} \\ \pi &= -0.0120 = -0''.032 \pm 0''.011 \end{aligned}$$

Probable error corresponding to unit weight $= \pm 0.0067 = \pm 0''.018$.

μ Orionis ($5^h 57^m$, $+9°39'$)

This star is interesting principally on account of its radial velocity. It is of spectral type A2, and according to Frost (*Astrophysical Journal*, **26**, 264, 1906) is a spectroscopic binary with a period of 0.77 day, the shortest period of any A-type star in Campbell's *Second Catalogue of Spectroscopic Binary Stars*. That this star is not a true member of the *Orion* group is shown by the fact that it has not an *Orion*-type spectrum, and also by the comparatively large radial velocity of +50 km per sec.

μ Orionis is β 1056 with a 14th-magnitude companion in position angle 272°.0 and distance 16''.8. According to Burnham, it is "probably only an optical double." Eight plates were obtained as described in Table 1. These plates were measured by Mr. Mitchell and the reductions were made at Columbia University by Miss Magill.

TABLE 1

PLATES OF μ *Orionis*

No.	Date			Hour Angle	Observers	Quality of Images
46	1907	Oct.	12	$+0^h.6$	Su, J, Su	Fair
85	1909	Jan.	17	+0.5	F, Su, F	Two fair
130		Oct.	16	−0.8	Su, Sl, Su	Good
140		Oct.	30	+0.1	Su, Sl, Su	Fair
219	1910	Feb.	27	+0.7	Su, Sl	Good
311		Oct.	1	−0.8	Sl, Sl	One fair
373	1911	Feb.	4	+1.5	Su, Sl	Poor
382		Mar.	4	+1.1	Su, Sl	Fair

On Plate 85, the aperture through mistake was 32 inches. Two images only were measured on this plate and one on Plate 311.

COMPARISON STARS

No.	Diameter	X (right ascension)	Y (declination)	Dependence
	mm			
8	0.23	−148	+329	+0.173
9	.27	−121	−102	.196
10	.22	− 70	−203	.205
15	.21	+134	−161	.218
16	.19	+205	+137	+0.208
Parallax star	0.13	+ 8.3	− 11.3	....

The average magnitude of the comparison stars is 9.3. The rotating disk was used to cut down the brightness of the parallax star.

TABLE 2

REDUCTIONS FOR μ *Orionis*

Plate	Solution (m)	Weight (p)	Parallax Factor (P)	Time in Days (t)	Residual (v)	$\sqrt{p}\cdot v$ in Arc
46	+0.114	0.9	+0.940	−617	−0.007	−0″.02
85	.118	0.7	− .463	−154	+0.020	+ .04
130	.126	1.2	+ .908	+118	+ .013	+ .04
140	.085	0.9	+ .783	+132	− .026	− .07
219	.086	1.0	− .926	+252	− .001	.00
311	.129	0.5	+ .989	+468	+ .018	+ .03
373	.090	0.4	− .707	+594	+ .003	+ .01
382	+0.071	0.7	− .950	+622	− .012	−0.03

The normal equations are:

$$6.3c+7.563\,\mu+0.9348\pi=+0.6491$$
$$97.6581\mu-8.3532\pi=+0.5607$$
$$4.6687\pi=+0.1667$$

These yield

$$c=+0.1023$$
$$\mu=-0.0010=-0''.003\qquad=-0''.001 \text{ per year}$$
$$\pi=+0.0134=+0''.036\pm0''.016$$

Probable error corresponding to unit weight $=\pm0.0115=\pm0''.031$

Groningen Area VII, No. 20 ($16^h21^m, +48°35'$)

This is a 10.7-magnitude star with a proper motion of 1″.22 per year. It is given as No. 20 in *Groningen Publications*, 19, pp. 100 and 114, and as No. 31 in *Groningen Publications*, 20, p. 131. Ten plates were secured as shown in Table 1. They were measured by Mr. Slocum.

TABLE 1

PLATES OF *Groningen Area VII, No. 20*

No.	Date	Hour Angle	Observers	Quality of Images	Remarks
395	1911 Apr. 1	-0^h5	Su	Good	
396	Apr. 8	-1.2	Sl	Good	
423	June 10	-0.3	Su	Good	
439	July 8	$-\ .1$	Su	Good	
700	1912 Mar. 17	$-\ .2$	Su, V	Good	One exposure
713	Mar. 21	$-\ .8$	Su, V	Good	One exposure
725	Apr. 2	$-\ .4$	Su, V	Good	One exposure
807	July 7	$-\ .7$	Su, Sl	Good	One exposure
812	July 13	$-\ .4$	M	Good	
818	July 14	-0.2	Su, Sl	Good	One exposure

COMPARISON STARS

No.	Diameter	X (right ascension)	Y (declination)	Dependence
	mm			
1	0.15	+308.0	+119.3	+0.18
2	.39	+278.0	−172.1	.16
3	.13	+221.8	+227.2	.18
4	.18	−138.2	+205.8	.175
5	.24	−329.6	−253.7	.15
6	.24	−340.0	−126.5	+0.155
Parallax star	0.26	+ 12.96	+ 12.90	......

The average magnitude of the comparison stars is approximately 9.5.

TABLE 2

REDUCTIONS FOR *Groningen Area VII, No. 20*

Plate	Solution (m)	Weight (p)	Parallax Factor (P)	Time in Days (t)	Residual (v)	$\sqrt{p}\cdot v$ in Arc
395	−1.003	0.7	+0.814	−265	−0.008	−0″02
396	−0.993	.7	+ .774	−258	− .003	− .01
423	− .966	.7	− .207	−195	− .008	− .02
439	− .925	.7	− .625	−167	+ .017	+ .04
700	− .541	.7	+ .921	+ 86	+ .020	+ .04
713	− .556	.7	+ .897	+ 90	+ .001	.00
725	− .556	.7	+ .797	+102	− .010	− .02
807	− .513	.7	− .622	+198	− .017	− .04
812	− .477	.7	− .697	+204	+ .015	+ .03
818	−0.501	0.7	−0.709	+205	−0.10	−0.02

The normal equations are:

$$\begin{aligned} 7.0c + 0.0000\mu + 0.9191\pi &= -4.9217 \\ +24.6014\mu - 3.0267\pi &= +2.8698 \\ +3.7191\pi &= -0.8474 \end{aligned}$$

from which

$$\begin{aligned} c &= -0.7093 \\ \mu &= +0.1224 = +0''.326 = +0^s.120 \text{ per year} \\ \pi &= +0.0471 = +0''.125 \pm 0''.012 \end{aligned}$$

Probable error corresponding to unit weight, $\pm 0.0084 = \pm 0''.022$. Kapteyn and DeSitter find $\pi = +0''.13$.

Anonymous ($17^h 33^m 51^s.2$, $+18°36'32''$ [1910.0])

While making the series of plates for the determination of the parallax of *B.D. 18°.3424*, this star attracted our attention both on account of its reddish color, and because of the fact that it does not appear in either the *B.D.* or *A.G.*, while fainter stars in the immediate vicinity are given in both catalogues. Its visual magnitude is 9.1.

At our request Professor Pickering took up the question of the variability of the star, and an examination of 16 plates, exposed between September 20, 1891, and September 1, 1910, showed no signs of change in brightness.

The series of plates for *B.D. 18°.3424* was measured by Miss M. M. Hopkins of Smith College. At first she included the suspicious star among the comparison stars, but it appeared to have a large proper motion and was therefore rejected. The subsequent measurement of four plates extending over 2.4 years gives for the proper motion of the star

$$\mu_\alpha = +0^s.065\,, \quad \mu_\delta = +1''.00$$

Its position for 1910.0 is $17^h 33^m 51^s.22$, $+18°36'31''.7$.

Although the star is some distance (13′) from the center of the plates, there are a number of stars around it suitable for comparison

TABLE I

PLATES OF *Anon.* ($17^h 33^m 51^s.2$, $+18°36'32''$ [1910.0])

No.	Date	Hour Angle	Observers	Quality of Images
499	1911 July 29	$0^h.0$	Su, Sl	Good
727	1912 Apr. 2	− .5	Sl, V	Good
730	1912 Apr. 7	− .3	V, Sl	Good
850	1912 Aug. 11	−0.2	Sl, Su	Good

COMPARISON STARS

No.	Diameter	X (right ascension)	Y (declination)	Dependence
	mm			
19	0.15	−195.1	+276.0	+0.22
11	.20	−153.9	− 77.4	+ .21
12	.19	−121.1	−261.0	+ .20
8	.17	+139.2	−134.3	+ .13
17	.16	+145.1	− 22.0	+ .13
3	.12	+185.8	+218.7	+0.11
Parallax star	0.26	− 41.95	− 5.42	......

purposes, so a preliminary value of its parallax has been determined from four plates described in Table 1. They were measured by Mr. Slocum.

The mean magnitude of the comparison stars is approximately 9.8.

TABLE 2

REDUCTIONS FOR *Anon.* ($17^h 33^m 51^s.2$, $+18° 36' 32''$ [1910.0])

Plate	Solution (m)	Weight (p)	Parallax Factor (P)	Time in Days (t)	Residual (v)	$\sqrt{p}\cdot v$ in Arc
449	−0.196	1	−0.676	−248	−0.001	0″.00
727	+ .115	1	+ .943	000	+ .007	+ .02
730	+ .104	1	+ .913	+ 5	− .008	− .02
850	+0.162	1	−0.829	+131	0.000	0.00

The normal equations are:

$$4.0c-1.120\mu+0.351\pi=+0.1850$$
$$7.869\mu+0.636\pi=+0.7035$$
$$+2.867\pi=+0.2016$$

from which

$$c=+0.0696$$
$$\mu=+0.0960=+0''.255 \qquad =+0^s.065 \text{ per year}$$
$$\pi=+0.0405=+0''.108\pm0''.011$$

Probable error corresponding to unit weight, $\pm0.0072=\pm0''.019$.

B.D. 18°.3423 ($17^h 34^m$, $+18° 37'$)

This is a 9.0-magnitude star which appears on the plates taken to determine the parallax of *B.D. 18°.3424*. This star was at first included among the comparison stars but was found to have an appreciable proper motion, and was therefore rejected in the investigation of *B.D. 18°.3424*. From the plates, $\mu_\alpha=-0^s.013$, $\mu_\delta=-0''.153$. From two observations given in the *Berlin A.G.*,

p. 129, the corresponding values are $\mu_\alpha = -0^s.012$, $\mu_\delta = -0''.13$. Nine plates were used as shown in Table 1. They were measured by Mr. Slocum.

TABLE 1

PLATES OF *B.D. 18°3423*

No.	Date	Hour Angle	Observers	Quality of Images
231	1910 Mar. 19	$-0^h.6$	Su, Sl	Fair
270	July 30	− .2	Su, Sl	Poor
408	1911 Apr. 22	−1.2	Sl, Su	Good
449	July 29	.0	Su, Sl	Good
727	1912 Apr. 2	− .5	Sl, V	Good
730	Apr. 7	− .3	V, Sl	Good
822	July 21	− .3	Su, Sl	Good
850	Aug. 11	− .2	Sl, Su	Good
857	Aug. 17	+0.6	Su, M	Fair

COMPARISON STARS

No.	Diameter	*X* (right ascension)	*Y* (declination)	Dependence
	mm			
11	0.20	−287.3	− 46.2	+0.24
13	.16	− 0.5	−173.7	.17
17	.16	+ 11.9	+ 9.2	.20
3	.12	+ 52.7	+250.0	.24
16	.24	+223.2	− 39.3	+0.15
Parallax star	0.24	− 19.82	+ 16.61	......

The mean magnitude of the comparison stars is approximately 9.7.

TABLE 2

REDUCTIONS FOR *B.D. 18°3423*

Plate	Solution (*m*)	Weight (*p*)	Parallax Factor (*P*)	Time in Days (*t*)	Residual (*v*)	$\sqrt{p}\cdot v$ in Arc
231	+0.826	0.7	+0.992	−497	+0.002	0''.00
270	.799	0.4	− .690	−364	+ .004	+ .01
408	.743	1.0	+ .792	− 98	+ .002	.00
449	.712	1.0	− .675	0	− .007	− .02
727	.673	1.0	+ .944	+248	+ .004	+ .01
730	.662	1.0	+ .914	+253	− .006	− .02
822	.650	1.0	− .580	+358	+ .005	+ .01
850	.640	1.0	− .828	+379	0	.00
857	+0.640	0.7	− .882	+385	+0.001	0.00

The normal equations are:

$$7.8c+9.1600\mu+0.3680\pi=+5.4258$$
$$+73.6584\mu-6.1607\pi=+5.0562$$
$$+5.2552\pi=+0.3992$$

from which

$$c=+0.7200$$
$$\mu=-0.0208=-0''.055 \qquad =-0^s.014 \text{ per year}$$
$$\pi=+0.0012=+0''.003\pm0''.004$$

Probable error corresponding to unit weight $\pm0.0033=\pm0''.009$.

B.D. 18°3424 (17^h34^m, $+18°37'$)

This is a star of magnitude 9.2 which, according to the *Berlin A.G.*, should have a proper motion of $1''.19$ per year. The plates, however, give a much smaller value, viz., $\mu_\alpha=+0^s.004$, $\mu_\delta=-0''.075$, or $\mu_s=0''.092$ in the direction 144°.75.

Twelve plates were secured as shown in Table 1. They were measured by Miss M. M. Hopkins of Smith College, who was a

TABLE 1

PLATES OF *B.D. 18°3424*

No.	Date	Hour Angle	Observers	Quality of Images
231	1910 Mar. 19	$-0^h.6$	Su, Sl	Good
244	1910 Apr. 9	$-.7$	Su, Sl	Fair
256	June 18	$-.6$	Su, Sl, H	Good
270	July 30	$-.2$	Su, Sl	Good
408	1911 Apr. 22	-1.2	Sl, Su	Good
443	July 8	-0.7	Su, Sl	Good
449	July 29	$.0$	Su, Sl	Fair
727	1912 Apr. 2	$-.5$	Sl, V	Fair
730	Apr. 7	$-.3$	V, Sl	Good
822	July 21	$-.4$	Su, Sl	Good
850	Aug. 11	$-.2$	Sl, Su	Good
857	Aug. 17	$+0.2$	Su, M	Fair

COMPARISON STARS

No.	Diameter	*X* (right ascension)	*Y* (declination)	Dependence
	mm			
8	0.17	−214.3	+ 92.3	+0.41
3	.12	−167.8	−261.0	.36
4	.15	+132.2	+170.1	.16
5	.20	+249.9	− 1.4	+.007
Parallax star	0.25	−108.28	− 29.20	......

volunteer research assistant at this observatory during the summer of 1912.

The mean magnitude of the comparison stars is approximately 9.7. Of the comparison stars originally selected two were found to have appreciable proper motions. These have been investigated separately. See the reduction of *B.D.* $18^\circ 3423$ and *Anon.* ($17^h 33^m$, $+18^\circ 36'$).

TABLE 2

REDUCTIONS FOR *B.D.* $18^\circ 3424$

Plate	Solution (m)	Weight (p)	Parallax Factor (P)	Time in Days (t)	Residual (v)	$\sqrt{p}\cdot v$ in Arc
231........	+1.286	1.0	+0.992	−476	−0.007	−0″.02
244........	1.305	0.7	+ .905	−455	+ .012	+ .03
256........	1.284	1.2	− .050	−385	− .011	− .03
270........	1.298	1.0	− .689	−343	+ .002	+ .01
408........	1.306	1.0	+ .793	− 77	− .003	− .01
443........	1.326	1.0	− .375	0	+ .015	+ .04
449........	1.326	0.7	− .674	+ 21	+ .015	+ .03
727........	1.324	0.7	+ .944	+269	+ .001	.00
730........	1.326	1.0	+ .914	+274	+ .003	+ .01
822........	1.328	1.0	− .578	+379	+ .002	+ .01
850........	1.324	1.0	− .827	+400	− .002	− .01
857........	+1.311	0.7	−0.881	+406	−0.016	−0.04

The normal equations are:

$$
\begin{aligned}
11.0c-1.3630\mu+0.3758\pi&=+14.4210\\
+121.8005\mu-9.4403\pi&=-\ \ 1.2914\\
+6.1431\pi&=+\ \ 0.4597
\end{aligned}
$$

from which

$$
\begin{aligned}
c&=+1.3115\\
\mu&=+0.0041=+0''.011 \qquad =+0''.003 \text{ per year}\\
\pi&=+0.0010=+0''.003\pm0''.008
\end{aligned}
$$

Probable error corresponding to unit weight, $\pm 0.0067=\pm 0''.018$.

96 Herculis ($17^h 58^m$, $+20^\circ 50'$)

This star is of magnitude 5.5 and is spectroscopically very interesting. It is of B type, and shows three separate components. Its spectrum has been investigated by Mitchell at the Yerkes Observatory. Preliminary measures were announced at the Ottawa meeting of the Astronomical and Astrophysical Society of America. For parallax determinations twelve plates were secured. They were measured by Mr. Mitchell.

TABLE 1

PLATES OF *96 Herculis*

No.	Date	Hour Angle	Observers	Quality of Images
271	1910 July 30	0^h0	Su, Sl	Poor
398	1911 Apr. 8	−1.4	Su, Sl	Fair
402	Apr. 15	−1.2	Su, Sl	Poor
409	Apr. 22	−1.1	Su, Sl	Good
467	Aug. 19	+0.4	Su, Sl	Fair
728	1912 Apr. 2	−0.3	Sl, V	Good
729	Apr. 2	−0.1	Sl, V	Fair
731	Apr. 7	−0.2	V, Sl	Good
823	July 21	−0.1	Su, Sl	Good
851	Aug. 11	+0.1	Su, Sl	Good
867	Aug. 25	−0.1	Sl, Su	Good
872	Aug. 31	+0.4	Su, M	Good

COMPARISON STARS

No.	Diameter	X (right ascension)	Y (declination)	Dependence
	mm			
1	0.10	−178	+135	+0.300
2	.14	− 14	−255	.348
3	.11	+ 25	+232	.154
4	.25	+167	−112	+0.198
Parallax star	0.14	− 21.4	− 34.7	....

The average magnitude of the comparison stars is 9.1. The rotating disk was used to cut down the brightness of the parallax star.

TABLE 2

REDUCTIONS FOR *96 Herculis*

Plate	Solution (*m*)	Weight (*p*)	Parallax Factor (*P*)	Time in Days (*t*)	Residual (*v*)	$\sqrt{p}\cdot v$ in Arc
271	+0.018	0.5	−0.616	−617	−0.020	−0.″04
398	.020	0.5	+ .948	−365	− .016	− .03
402	.050	0.4	+ .905	−358	+ .013	+ .02
409	.052	1.0	+ .849	−351	+ .015	+ .04
467	.052	0.7	− .842	−232	+ .012	+ .03
728	.032	1.0	+ .972	− 5	− .006	− .02
729	.025	0.7	+ .972	− 5	− .013	− .03
731	.046	1.0	+ .950	0	+ .008	+ .02
823	.033	1.0	− .497	+105	− .008	− .02
851	.050	1.0	− .769	+126	+ .008	+ .02
867	.048	0.9	− .898	+140	+ .006	+ .02
872	+0.035	1.0	−0.939	+146	−0.008	−0.02

The normal equations are:

$$
\begin{aligned}
9.7c - 6.5283\mu + 0.3754\pi &= +0.3854\\
53.4934\mu - 6.8135\pi &= -0.2258\\
7.1429\pi &= +0.0001
\end{aligned}
$$

These yield

$$
\begin{aligned}
c &= +0.0401\\
\mu &= +0.0005 = +0''.001 \quad = +0^s.000 \text{ per year}\\
\pi &= -0.0016 = -0''.004 \pm 0''.008
\end{aligned}
$$

Probable error corresponding to unit weight $= \pm 0.0078 = \pm 0''.021$.

17 Lyrae C ($19^h 4^m$, $+32°21'$)

This is a faint star with large proper motion, $1''.752$ per year, discovered by Burnham near *17 Lyrae* ($19^h 4^m$, $+32°21'$). See *M.N.*, **68**, 517, and *M.N.*, **71**, 208. The visual magnitude of *C* is 11.3, the photographic magnitude 12.5. Nine plates were obtained at six parallactic epochs as shown in Table 1. They were measured by Mr. Slocum.

TABLE 1

PLATES OF *17 Lyrae C*

No.	Date	Hour Angle	Observers	Quality of Images
10A	1907 June 11	$-2^h.0$	F	Good
77	1908 Nov. 28	+3.6	F, A	Good
90	1909 Mar. 20	−1.7	F	Good
105	Sept. 11	0.0	Sl	Fair
245	1910 Apr. 9	−1.4	Su	Good
252	May 14	−0.3	Su	Good
280	Aug. 6	−0.2	Su	Good
282	Aug. 20	−0.4	Sl, Su	Good
288	Aug. 26	−0.4	Su, Su	Fair

COMPARISON STARS

No.	Diameter	*X* (right ascension)	*Y* (declination)	Dependence
	mm			
1	0.23	−188.2	+ 89.9	+0.15
3	.36	− 94.5	− 23.1	.28
6	.17	− 1.2	− 68.8	.31
2	.27	+ 54.6	+ 67.1	.07
5	.32	+229.3	− 65.1	+0.19
Parallax star	0.17	− 6.00	− 22.20	......

The mean magnitude of the comparison stars is approximately 10.2.

TABLE 2

REDUCTIONS FOR *17 Lyrae C*

Plate	Solution (m)	Weight (p)	Parallax Factor (P)	Time in Days (t)	Residual (v)	$\sqrt{p}\cdot v$ in Arc
10A.......	+0.604	0.7	+0.418	−844	+ .007	+ ″02
77........	1.232	1.0	−0.608	−308	− .008	− .02
90........	1.462	.7	+0.959	−196	+ .005	+ .01
105........	1.584	.5	−0.899	− 21	− .012	− .02
245........	1.954	.7	+0.992	+189	− .001	.00
252........	1.978	.7	+0.781	+224	− .010	− .02
280........	2.048	.7	−0.490	+308	+ .009	+ .02
282........	2.050	1.0	−0.679	+322	+ .002	+ .01
288........	+2.061	0.7	−0.749	+328	+ .008	+0.02

The normal equations are:

$$\begin{aligned}6.7c+0.0980\mu-0.3988\pi&=+11.1489\\+92.6136\mu-4.2438\pi&=+11.9000\\+3.6775\pi&=-1.0397\end{aligned}$$

from which

$$\begin{aligned}c&=+1.6649\\\mu&=+0.1289=+0\overset{\prime\prime}{.}343\quad=+0\overset{s}{.}099\text{ per year}\\\pi&=+0.0465=+0\overset{\prime\prime}{.}124\pm0\overset{\prime\prime}{.}008\end{aligned}$$

Probable error corresponding to unit weight, $\pm0.0052=\pm0\overset{\prime\prime}{.}014$.

P Cygni ($20^h 14^m$, $+37°43'$)

"This previously unrecorded star was discovered by Janson on August 18, 1600. It was observed by Kepler two years later when it was of the third magnitude, and it remained visible to the eye until 1621. Cassini found it to be of the third magnitude for a short time in 1655, and, after another less-marked rise in 1665, it slowly declined in brightness. Since 1677, the light of the star has been very nearly constant, at magnitude 5.0" (Frost, *Astrophysical Journal*, **35**, 286, 1912). The spectrum, examined by Frost (*loc. cit.*), is of the B type, but peculiar in showing intense, broad, bright lines of hydrogen and helium.

Eleven plates of this star were obtained for parallax determinations as given in Table 1. They were measured by Mr. Mitchell.

TABLE 1

PLATES OF *P Cygni*

No.	Date	Hour Angle	Observers	Quality of Images
281	1910 Aug. 13	$-1^h.5$	Su, Sl	One fair
283	Aug. 20	−0.6	Su, Sl	Good
289	Aug. 26	−0.4	Su, Su	Good
297	Sept. 9	−1.0	Su, Su	One fair
304	Oct. 1	−0.5	Sl, Sl	Good
317	Oct. 15	−0.2	Sl, Sl	Poor
428	1911 June 17	−1.6	Su, Sl	Good
513	Oct. 7	−0.6	Sl, Sl	Fair–Good
760	1912 May 16	−1.6	Su, Sl	Good
761	May 16	−1.4	Su, Sl	Good
792	June 22	+0.2	Su, Sl	Good

Plates 297 and 428 were each measured twice.

COMPARISON STARS

No.	Diameter	X (right ascension)	Y (declination)	Dependence
	mm			
1	0.18	−293	− 65	+0.168
2	.16	−136	+126	.205
4	.18	+ 65	−148	.187
5	.19	+114	− 7	.208
6	.15	+250	+ 94	+0.232
Parallax star	0.17	+ 16.8	+ 7.7	....

The average magnitude of the comparison stars is 9.5. The rotating disk was used to cut down the light of the parallax star.

TABLE 2

REDUCTIONS FOR *P Cygni*

Plate	Solution (m)	Weight (p)	Parallax Factor (P)	Time in Days (t)	Residual (v)	$\sqrt{p}\cdot v$ in Arc
281	+.042	0.5	−0.324	−339	− .019	−0″.03
283	.072	1.0	− .430	−332	+ .010	+ .03
289	.066	1.0	− .516	−326	+ .004	+ .01
297	.055	0.7	− .696	−312	− .009	− .02
304	.052	1.0	− .896	−290	− .013	− .03
317	.074	0.4	− .958	−276	+ .008	+ .01
428	.060	1.2	+ .575	− 31	+ .008	+ .02
513	.080	0.8	− .928	+ 81	+ .016	+ .04
760	.043	1.0	+ .896	+303	− .005	− .01
761	.060	1.0	+ .896	+303	+ .012	+ .03
792	+0.063	1.0	+0.495	+340	−0.018	−0.05

The normal equations are:

$$\begin{aligned} 9.6c-4.727\,\mu-\ 0.6398\pi &= +0.5511 \\ 76.2292\mu+15.1326\pi &= -0.4242 \\ +\ 4.9490\pi &= -0.0829 \end{aligned}$$

These yield

$$\begin{aligned} c &= +0.0566 \\ \mu &= -0.0004 = -0\overset{''}{.}001 \qquad = -0\overset{s}{.}000 \text{ per year} \\ \pi &= -0.0080 = -0\overset{''}{.}021 \pm 0\overset{''}{.}016 \end{aligned}$$

Probable error corresponding to unit weight $= \pm 0.0087 = \pm 0\overset{''}{.}023$.

τ Cygni (21^h10^m, $+37°37'$)

This is a 3.8-magnitude star discovered in 1874 to be double by Alvan G. Clark with the 26-inch of the Leander McCormick Observatory. The components *A* and *B* of 4.9 and 7.4 magnitudes are separated approximately 1″. Since the discovery, the companion has passed over 270° of position angle. The period is 55± years. The system has a proper motion, according to Boss, of 0″455 in position angle 20°3. 15″ distant is a fainter component.

τ *Cygni* is of spectral type F, and was found by Barrett to be a spectroscopic binary (*Astronomische Nachrichten*, **177**, 174, 1908). According to the above conditions, it is reasonable to expect τ *Cygni* to possess an appreciable parallax. G. Abetti has

TABLE I

PLATES OF τ *Cygni*

No.	Date	Hour Angle	Observers	Quality of Images
112	1909 Sept. 18	0^h0	Su, Sl, Su	Fair
259	1910 June 18	−1.0	Su, Sl	Fair
268	June 25	−1.4	Su, Sl	Good
299	Sept. 9	−0.4	Su, Su	Good
328	Oct. 22	0.0	Sl, Sl	Fair
430	1911 June 17	−1.7	Su, Sl	Good
444	July 8	−0.7	Su, Sl, Sl	Good
482	Sept. 2	−0.4	Su, Sl	Good
495	Sept. 16	−0.1	Su, Sl	Good
779	1912 June 8	−0.5	Su, Sl	Good
793	June 22	−0.4	Su, Sl	Fair
794	June 22	−0.1	Su, Sl	Good
797	June 23	0.0	M, Su	One good

Plate 797 was measured twice.

COMPARISON STARS

No.	Diameter	X (right ascension)	Y (declination)	Dependence
	mm			
1............	0.15	−285	−149	+0.253
2............	.23	− 29	+214	.269
4............	.16	+130	−243	.223
5............	.20	+184	+178	+0.255
Parallax star..	0.26	− 3.9	+ 11.0	....

published (*Mem. Soc. Spettros. Italiani*, November, 1912) an interesting discussion of τ *Cygni*, in which he assumes a parallax of 0\".06.

Thirteen plates of the star were obtained. These were measured by Mr. Mitchell.

The average magnitude of the comparison stars is 9.5. The rotating disk which was used to reduce the brightness of the parallax star cut out both companion stars.

TABLE 2

REDUCTIONS FOR τ *Cygni*

Plate	Solution (m)	Weight (p)	Parallax Factor (P)	Time in Days (t)	Residual (v)	$\sqrt{p}\cdot v$ in Arc
112........	+0.077	0.9	−0.619	−504	+ .005	+0\".01
259........	.102	0.7	+ .724	−201	− .014	− .03
268........	.094	1.0	+ .645	−224	− .022	− .06
299........	.155	1.0	− .498	−148	+ .030	+ .08
328........	.104	0.7	− .911	−105	− .026	− .06
430........	.192	1.0	+ .738	+133	+ .023	+ .06
444........	.183	1.2	+ .477	+154	+ .011	+ .03
482........	.176	1.0	− .394	+210	− .002	− .01
495........	.170	1.0	− .588	+224	− .010	− .03
779........	.219	1.0	+ .816	+490	− .003	− .01
793........	.234	0.7	+ .674	+504	+ .010	+ .02
794........	.214	1.0	+ .674	+504	− .010	− .03
797........	+0.219	0.8	+0.662	+505	−0.005	−0.01

The normal equations are:

$$12.0c + 14.418\,\mu + 2.2788\pi = +1.9921$$
$$+136.2136\mu + 13.7651\pi = +4.1753$$
$$+ 5.0641\pi = +0.5524$$

These yield

$$c = +0.1478$$
$$\mu = +0.0148 = +0''.039 \qquad = +0^s.012 \text{ per year}$$
$$\pi = +0.0024 = +0''.0065 \pm 0''.016$$

Probable error corresponding to unit weight $= \pm 0.0117 = \pm 0''.031$.

The determinations of the parallax of *τ Cygni* have been made by meridian circle.

Belopolsky obtains $\pi = +0''.06 \pm 0''.06$
Jost obtains $\pi = +0''.125 \pm 0''.063$
Abetti obtains $\pi = +0''.029 \pm 0''.039$

Nova Lacertae ($22^h 32^m$, $+52° 12'$)

Nova Lacertae was discovered by Espin, December 30, 1910. A preliminary value of its parallax was published in *Astrophysical*

TABLE I

PLATES OF *Nova Lacertae*

No.	Date	Hour Angle	Observers	Quality of Images	Remarks
359	1910 Dec. 31	$+2^h.8$	Sl, Sl	Fair	Telescope east
360	1911 Jan. 7	+2.8	Sl, Sl, Sl	Good	Telescope east
432	June 17	−2.0	Su, Sl	Good	
438	July 1	− .6	Su	Fair	
446	July 8	− .5	Su, Sl	Good	
498	Sept. 16	.0	Sl, Su	Good	
531	Oct. 14	− .2	Sl, Su	Good	
536	Oct. 28	− .5	Su, Sl	Good	
548	Nov. 21	− .1	Sl, Sl	Good	
563	Dec. 1	− .2	Sl, Sl	Good	
802	June 29	− .9	Su, Sl	Fair	
810	July 7	− .4	Su, M	Fair	
816	July 13	0.0	Su	Poor	

COMPARISON STARS

No.	Diameter	X (longitude)	Y (latitude)	Dependence
	mm			
1	0.32	−261.6	− 77.2	+0.13
2	.22	− 76.5	+179.8	.21
3	.21	− 65.8	− 28.2	.15
4	.30	− 20.8	+ 42.8	.18
5	.24	+ 55.3	−247.5	.11
6	.27	+369.4	+130.3	+0.22
Nova	0.37 to 0.10	+ 23.46	+ 32.17	......

Journal, 35, 134. Since that determination was made, the observations have been extended over one more parallactic epoch, and, in all, thirteen plates obtained, as shown in Table 1. They were measured by Mr. Slocum.

The mean magnitude of the comparison stars is approximately 9.3.

TABLE 2

REDUCTIONS FOR *Nova Lacertae*

Plate	Solution (m)	Weight (p)	Parallax Factor (P)	Time in Days (t)	Residual (v)	$\sqrt{p}\cdot v$ in Arc
359........	0.000	0.7	−0.983	−189	−0.009	−0″.02
360........	+ .002	1.2	−0.978	−182	− .007	− .02
432........	.024	1.0	+0.984	− 21	+ .004	+ .01
438........	.047	.5	+1.016	− 7	+ .026	+ .05
446........	.000	1.0	+1.012	0	− .022	− .06
498........	.036	1.0	+0.299	+ 70	+ .013	+ .04
531........	.046	1.0	−0.176	+ 98	+ .023	+ .06
536........	.036	1.0	−0.405	+112	+ .013	+ .04
548........	.001	1.0	−0.736	+136	− .022	− .06
563........	.029	1.0	−0.838	+146	+ .006	+ .02
802........	.012	.7	+1.015	+357	− .024	− .05
810........	.047	.7	+1.012	+365	+ .010	+ .02
816........	+0.023	0.3	+0.998	+371	−0.014	−0.03

The normal equations are:

$$
\begin{aligned}
11.1c+\ 8.0350\mu+0.5053\pi&=+0.2461\\
+35.5843\mu+6.7885\pi&=+0.3189\\
+7.5993\pi&=+0.0569
\end{aligned}
$$

from which

$$
\begin{aligned}
c&=+0.0190\\
\mu&=+0.0042=+0''.011\\
\pi&=+0.0025=+0''.007\pm0''.012
\end{aligned}
$$

Probable error corresponding to unit weight $\pm0.0116=\pm0''.031$.

Belanowsky[1] finds, by photography, $\pi=-0''.005\pm0''.020$.

The following table (p. 25) gives a summary of the results. The *absolute* values of the parallaxes can be found only when we know the parallaxes of the comparison stars. At present only approximate average values are available for comparison stars of different

[1] *Mitteilungen der Nikolai-Hauptsternwarte zu Pulkowo*, 5, pt. 4, 47.

SUMMARY OF RESULTS

Star	R.A. 1900	Decl. 1900	*B.D.* Number	Magnitude and Spectrum	Proper Motion	Relative Parallax	Probable Error	Co-ord.	No. of Plates	Probable Error of One Plate
φ Andromedae	1^h 4^m	+46° 43′	+46.275	4.4 B 8	0″.03	+0″.004	±0″.008	Long	8	±0″.019
48 Cassiopeiae	1 54	+70 25	+70.153	4.6 A2	0.06	−0.002	0.016	Long	10	0.036
20 Persei	2 47	+37 56	+37.655	5.7 F	0.10	−0.012	0.007	R.A.	13	0.018
9 Camelopardalis	4 44	+66 10	+66.358	4.4 B	0.01	−0.032	0.011	R.A.	10	0.018
μ Orionis	5 57	+ 9 39	+9.1064	4.2 A2	0.03	+0.036	0.016	R.A.	8	0.031
Groningen VII, No. 20	16 21	+48 35	....	10.7	1.22	+0.125	0.012	R.A.	10	0.022
Anonymous	17 33	+18 37	....	9.1	1.36	+0.108	0.011	R.A.	4	0.019
B.D. 18°3423	17 34	+18°37	+18.3423	9.0	0.24	+0.003	0.004	R.A.	9	0.009
B.D. 18°3424	17 34	+18°37	+18.3424	9.2	0.09	+0.003	0.008	R.A.	12	0.018
96 Herculis	17 58	+20 50	+20.3649	5.5 B	0.02	−0.004	0.008	R.A.	12	0.021
17 Lyrae C	19 4	+32 21	....	11.3	1.75	+0.124	0.008	R.A.	9	0.014
P Cygni	20 14	+37 43	+37.3871	4.9 B4P	0.01	−0.021	0.016	R.A.	11	0.023
τ Cygni	21 10	+37 37	+37.4240	3.8 F	0.45	+0.006	0.016	R.A.	13	0.031
Nova Lacertae	22 32	+52°12	....	8 to 13 P	....	+0.007	±0.012	Long	13	±0.031

magnitudes. From Kapteyn's table in *Groningen Publications*, No. 24, p. 15, we have

Galactic Latitude Mean Magnitude Comp. Stars	−20° to +20°	±20° to ±40°	±40° to ±90°
8.0	+0″006	+0″007	+0″009
9.0	.005	.006	.007
10.0	.004	.005	.005
11.0	+0.003	+0.004	+0.004

The mean magnitude of the comparison stars for our various fields ranges from 8.9 to 10.5, so if the mean parallax of the five or six comparison stars which we have used in each case conforms to the above table of averages, the corrections necessary to reduce our *relative* parallaxes to *absolute* parallaxes will range from +0″004 to +0″006.

YERKES OBSERVATORY
January 1913

PRELIMINARY RESULTS OF AN ATTEMPT TO DETECT THE GENERAL MAGNETIC FIELD OF THE SUN[1]

By GEORGE E. HALE

INTRODUCTION

The investigation[2] of the magnetic phenomena of rotating bodies dates from the classic experiment of Rowland, who in 1876 succeeded in producing a magnetic field by whirling an electrically charged disk at a high velocity.[3] Maxwell had previously suggested the hypothesis that an electrified body in motion is equivalent to an electric current, and calculated the strength of the field thus obtained,[4] but definite proof of the effect was lacking prior to Rowland's demonstration.

In 1879 Perry and Ayrton showed that since points near the surface of the earth have linear velocities of rotation different from those of the interior, a magnetic field would be produced if the earth had an initial electrical charge residing on the surface.[5] The weak point in this theory of terrestrial magnetism, as Rowland pointed out in the same year, lies in the fact that the earth must be electrified to a potential of about 41×10^{15} volts to account for the observed field. As this would be sufficient to produce a spark about six million miles long in atmospheric air of ordinary density, and would enter as a serious factor in planetary perturbations, it is evident that the theory must be dropped.[6]

In 1891 and again in 1892 Schuster raised the question whether

[1] *Contributions from the Mount Wilson Solar Observatory*, No. 71.

[2] The first results of this investigation may be found in "Pieliminary Note on an Attempt to Detect the General Magnetic Field of the Sun," *Terrestrial Magnetism and Atmospheric Electricity*, **17**, 173, 1912.

[3] Rowland, "On the Magnetic Effect of Electric Convection," *American Journal of Science* (3), **15**, 30–38, 1878.

[4] Maxwell, "Treatise on Electricity," Art. 770.

[5] Perry and Ayrton, "A New Theory of Terrestrial Magnetism," *Proc. Physical Society of London*, **3**, 57, 1879.

[6] Rowland, "On Professors Ayrton and Perry's New Theory of the Earth's Magnetism," *Proc. Physical Society of London*, **3**, 97, 1879.

every large rotating mass is not a magnet.[1] Lord Kelvin also forcibly expressed his opinion that the earth's magnetism must be due to its rotation. In 1894 J. J. Thomson remarked that if atoms exert different attractions on positive and negative electricity, then a large rotating body ought to produce a magnetic field. The maximum magnetic force at the surface of a rotating sphere would be proportional to ρr^2, where ρ is the angular velocity of rotation and r the radius. Assuming the earth's magnetic force to be the maximum attainable by the rotation of a sphere the size of the earth, he calculated that the magnetic force of a sphere one foot in radius rotating one hundred times a second would be about one hundred-millionth part of that of the earth. Hence it would probably be hopeless to detect such an effect in the laboratory.[2] Sutherland applied this idea in his hypothesis of terrestrial magnetism, and pointed out that the external electric effect would be overcome by the presence within the earth of equal charges of positive and negative electricity. These he supposed to be spread over concentric spheres whose radii differ by a very small quantity.

In a paper read before the American Association on December 31, 1912, Bauer adopts a similar view. The symmetrical part of the earth's field can then be accounted for by supposing the radius of the sphere containing the positive charge to be only 0.4×10^{-8} cm smaller than that of the sphere containing the negative charge. This difference is about four-tenths of the radius of a molecule.[3] A similar result is obtained for the portion of the earth's field due to the effect of the atmosphere—the negative electrons, on the average, are somewhat farther from the earth's center than the positive electrons. If the positive and negative electrons differ in mass and possess inertia, the earth's centrifugal force may produce a spheroidal rather than a spherical distribution of the charges, thus accounting for the observed increase in the equivalent intensity of magnetization toward the equator. Assuming the sun's field to be due to the same cause as that of the earth, Bauer computes

[1] *Report, B.A.A.S.* for 1892, p. 634; *Proc. Physical Society of London*, **24**, 121, 1912.

[2] "On the Electricity of Drops," *Phil. Mag.* (5), **37**, 358, 1894.

[3] Wilson, "Structure of Atoms," *Science*, N.S., **35**, 511, 1912.

that the vertical magnetic intensity at the sun's poles is about 300 gausses.[1] This value is in close agreement with that of Schuster, who had previously shown that the magnetic intensity of the sun should be about 440 times greater than that of the earth.[2]

A very different theory, which is preferred by Schuster, rests on the probable assumption that every molecule is a magnet. If this magnetism is accounted for as the effect of the rapid revolution of electrons within the molecule, a gyrostatic action may be anticipated. That is, each molecule would tend to set itself with its axis parallel to the axis of the earth, and the earth's magnetic field would result from the combined effect of all the molecules.

This theory, like the preceding one, is not free from obvious points of weakness. Its chief advantage lies in the possibility that it may explain the secular variation of the earth's magnetism by a precessional motion of the magnetic molecules.

As a general problem of physics, the suggestion of Schuster that every rapidly rotating body may produce a magnetic field is of fundamental importance. Since it appears to be beyond the reach of experimental test, owing to the limitations of size and rotational velocity imposed by laboratory conditions, we may take advantage of astronomical phenomena, where these limitations no longer obtain. The existence of the earth's magnetism is favorable to the hypothesis, but it remains to be determined by the observation of other heavenly bodies whether such magnetic phenomena as they may exhibit are in harmony with its assumptions. The most

[1] I am indebted to Dr. Bauer for the manuscript of an abstract of this paper, which has since appeared in the *Physical Review*. See also "A Consistent Theory of the Origin of the Earth's Magnetic Field," *Journal Washington Academy of Sciences*, January 4, 1913.

[2] Schuster, "A Critical Examination of the Possible Causes of Terrestrial Magnetism," *Proc. Physical Society of London*, **24**, 127, 1912. In this paper, and in a later one by Swann ("The Earth's Magnetic Field," *Phil. Mag.*, **24**, 80, 1912) various theories of the earth's magnetism are fully discussed. Schuster rejects the hypothesis that a neutral molecule in its motion behaves as if it carried a charge, partly because of the distinction which must be made between the magnetic effects of a rotating body on a fixed magnet and on one moving with it, and also on account of the failure of this hypothesis to explain the secular variation and the lack of coincidence of the magnetic and geographical axes. I am indebted to Professor Schuster for the results of his calculations of the strength of the sun's general field, communicated to me in September 1911, before their publication.

promising opportunity is afforded by the sun, which meets many of the necessary conditions. Its great radius and angular velocity of rotation should give rise to a field more than four hundred times as intense as that of the earth. Its atmosphere contains self-luminous vapors, giving line-spectra capable of revealing the magnetic field by the Zeeman effect. Its brightness is sufficient to permit the use of the very high dispersion required to detect a field so much weaker than the fields usually employed in laboratory studies of radiation. Finally, its axial rotation and large angular diameter facilitate observation at a great number of points on its surface, while the position of its axis, allowing line displacements to be measured near both poles, enables the observer to apply the most perfect test of the Zeeman effect—the reversal of the sign of the displacement with the polarity. A very important limitation, however, must not be overlooked. We know that the sun contains free electrons, and that the positive and negative charges are definitely segregated in sun-spots and probably also in the chromosphere, where the more active negative electrons tend toward higher levels. Hence magnetic fields, local and general, may result from the motion of these charges. It is possible, nevertheless, to determine accurately the part played by free electrons in spots, and their effect on the general magnetic field may not be beyond the range of investigation.

From the standpoint of the physicist, therefore, the sun may prove of service by throwing some light on the hypothesis of the magnetism of rotating bodies. But the problem is of no less interest and importance from an astrophysical point of view. The discovery of powerful magnetic fields in sun-spots[1] indicated the possibility of a general observational attack on solar magnetic phenomena. The Zeeman effect was found to extend well beyond the limits of the penumbra, and the configuration of the hydrogen flocculi suggested that with suitable polarizing apparatus local fields, sometimes of great extent, might be detected in regions far removed from visible spots. The next logical step was the exploration of the sun's general field.

[1] *Contributions from the Mount Wilson Solar Observatory*, No. 30; *Astrophysical Journal*, **28**, 315–343, 1908.

So far as I am aware, the only direct method of detecting the magnetic field of the sun is by the observation of the Zeeman effect. An indirect method, first applied by Bigelow to the corona in 1889, led him to infer that the sun must be a magnet because the coronal streamers, especially near the poles, agree well in form with the lines of force of a magnetized sphere.[1] Störmer has recently calculated the trajectories of electric corpuscles moving out from the sun under the influence of an assumed magnetic field, and the resulting curves closely resemble the structure of the corona.[2] Finally, Deslandres has applied the same idea in the case of the prominences, and concludes from their forms and radial velocities that the ions which compose them are moving under the influence of the sun's field.[3] The results already obtained by these methods are of extreme interest, and promise to be of even greater importance when fully developed in the future. It should be noted, however, that any conclusions thus reached as to the sun's general field must relate to the field existing at considerable elevations in the solar atmosphere, which may differ greatly in intensity, and may even be opposed in sign, to the field produced by the rotation of the body of the sun lying within the photosphere. Furthermore, since the sign of the charge of the outflowing electrons must be assumed, and since this sign may not always be the same, no certain conclusion can be reached as to the polarity of the general field or the sign of the charge that may produce it, even when the velocity of the electrons is accurately known.

These and other considerations led Schuster, when summing up the situation in April 1912, to remark: "The evidence [whether the sun is a magnet] rests entirely on the form of certain rays of the corona, which—assuming that they indicate the path of projecting particles—seem to be deflected as they would be in a magnetic field, but this evidence is not at all decisive."[4]

[1] Bigelow, "The Solar Corona," Smithsonian Institution, 1889.

[2] Störmer, "Sur la structure de la couronne du soleil," *Comptes Rendus*, February 20, 1911.

[3] See several papers by Deslandres in the *Comptes Rendus*, the chief results of which are given in "Champ magnétique général des couches supérieures de l'atmosphère solaire. Vérifications nouvelles." *Comptes Rendus*, December 30, 1912.

[4] Schuster, *op. cit.*, p. 131.

METHOD OF OBSERVATION

The observations were begun in 1908 with the 30-foot spectrograph of the 60-foot tower telescope.[1] This instrument served admirably for the strong magnetic fields (maximum strength about 4500 gausses) in sun-spots, but the polarizing apparatus was not well adapted for an investigation of extremely weak fields. Certain minute displacements of the solar lines, such as would have been caused by a general magnetic field, were found on measuring the

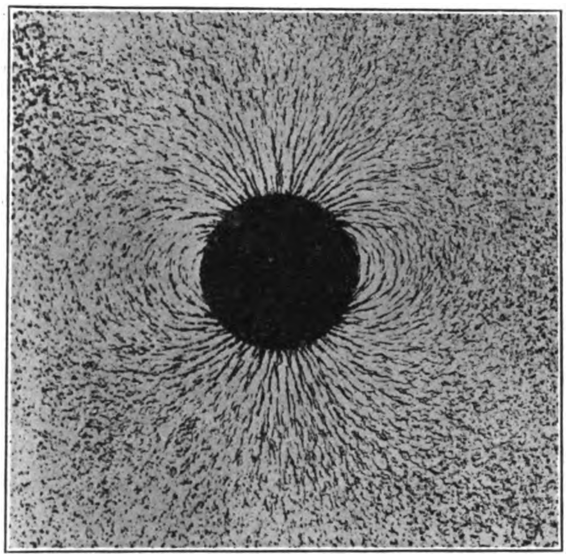


FIG. 1.—Lines of force of a magnetized sphere

photographs, but these were not such as to command confidence, and further work was deferred until better polarizing apparatus should become available. The great solar activity at that time, giving rise to strong magnetic fields in sun-spots and their neighborhood, was another adverse factor. During the present minimum of activity, sun-spots and other disturbances are rarely observed, and the unusually quiet condition of the solar atmosphere is precisely what is needed for an investigation of this nature.

[1] *Publications Astronomical Society of the Pacific*, **20**, 287, 1908.

Let us assume the sun's magnetic field to be similar to that of a magnetized sphere, with magnetic poles corresponding in position with the poles of rotation. The lines of force would then appear as in Fig. 1, the angle δ between them and the solar surface being given by the expression

$$\tan \delta = 2 \tan \phi$$

when ϕ is the heliocentric latitude. If the field were strong enough, and if the observer could look along the sun's axis and form an image of the one of the magnetic poles on the slit of a powerful spectrograph, he would find certain solar lines split into doublets, with components circularly polarized in opposite directions. If a Nicol prism were placed in front of the slit of the spectrograph with its long axis parallel to the slit, in combination with a quarter-wave plate set with its principal section at an angle of 45°, one of the components of the magnetic doublets would be extinguished while the other would be transmitted by the Nicol, as in the case of a sun-spot. Assuming the red component to be transmitted, rotation of the quarter-wave plate through an angle of 90° would cause this to be extinguished and the violet component to be transmitted. Consequently, if the quarter-wave plate were built up of mica strips 2 mm wide, mounted so that the principal sections of successive strips make an angle of 45° with the slit and 90° with each other, the Nicol would transmit (say) the red component for the odd strips and the violet component for the even strips. In a photograph of the spectrum the lines would have a dentated appearance, the magnitude of the separation of the components shown on successive strips varying directly with the strength of the field. If, from the same place of observation, the slit of the spectrograph were directed, not at the sun's pole, but at a point in 45° latitude, the effect would still be clearly observable, though the transformation of the circularly polarized light of the components into elliptically polarized light would result in less complete extinction by the Nicol.

In practice, on account of the weakness of the sun's magnetic field as compared with the fields of sun-spots, complete separation into doublets is not to be expected. Moreover, the terrestrial observer, who is close to the plane of the sun's equator, must look in

a direction nearly at right angles to the lines of force at the sun's poles. Thus he cannot take full advantage of the fact that the total intensity of the sun's magnetization is twice as great at the poles as at the equator. Fortunately, however, the angle between the lines of force and the line of sight (for an observer in the plane of the solar equator) is reduced to zero at 35° north or south latitude. But the most favorable position for observation is latitude 45°, where the effect of the ellipticity of the light of the components is overcome by the increased strength of the field.[1] It was hoped that in this latitude a spectrograph of very high dispersion might reveal slight shifts of the lines, caused by the extinction of the red and violet components by the successive strips of the quarter-wave plate. The increasing ellipticity of the *n*-components below 35°, coupled with the increasing strength of the *p*-component of triplets, and the decrease in the total intensity of the field toward the equator would be indicated by decreasing displacements of the lines. Toward the poles, for similar reasons, the displacements should also decrease.

When a source of light is between the poles of a magnet, and one of its components (observed along the lines of force) is cut off by a quarter-wave plate and Nicol, reversal of the current through the magnet extinguishes the visible component and causes the other to appear. Hence, in the case of the sun's general field, the sign of the displacements should be reversed in passing from the northern to the southern hemisphere, on account of the change of polarity.[2]

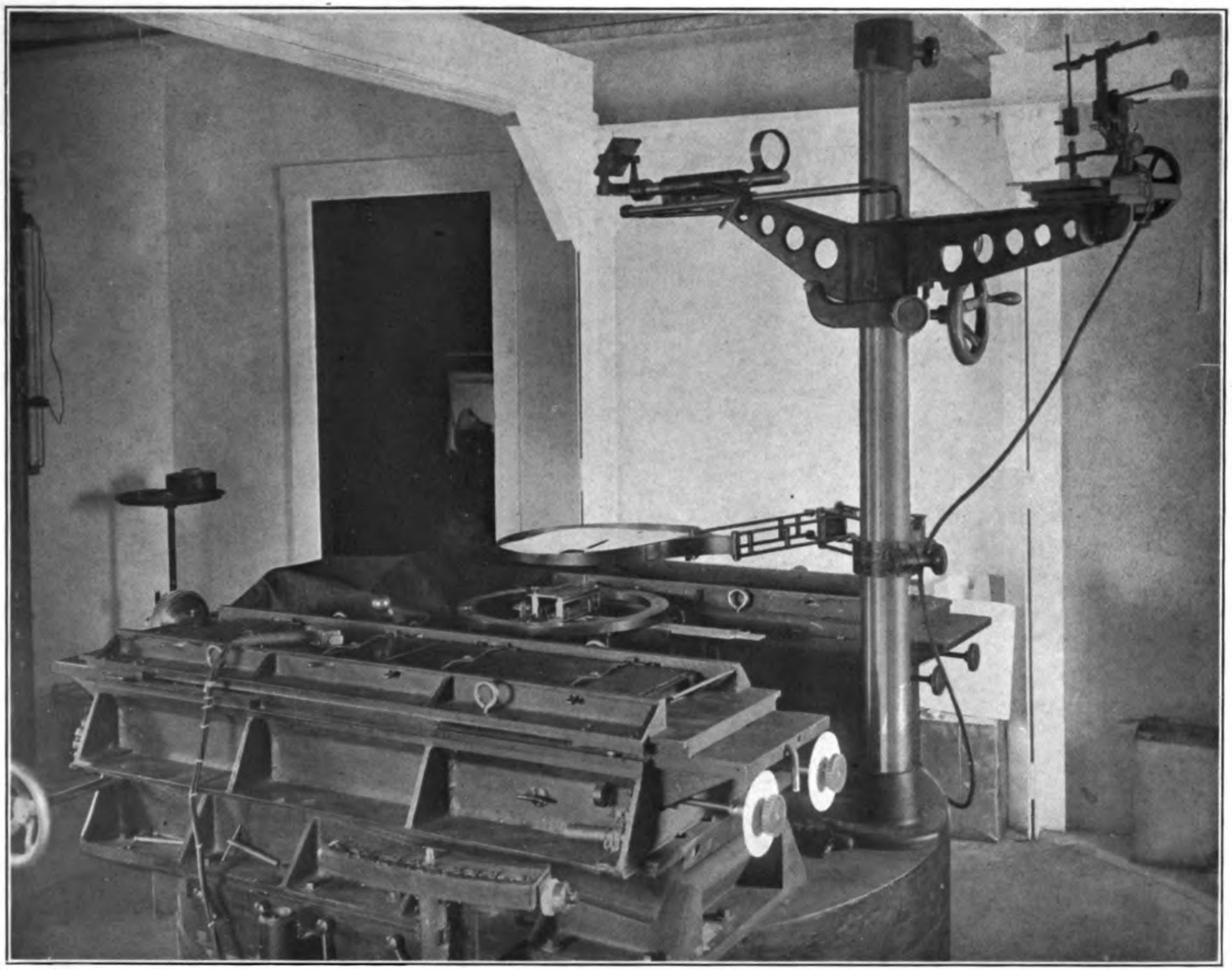
The investigation was resumed in October 1911 with the polarizing apparatus described above mounted over the slit of the 30-foot spectrograph of the 60-foot tower telescope, but no displacements which could safely be attributed to the sun's field were detected. Fortunately, the completion of the 75-foot spectrograph of the 150-foot tower telescope soon provided a much more powerful instrument, especially adapted for the purposes of this investigation.

A coelostat mounted at the summit of a tower 164 feet (50 m) in height sends a beam of sunlight to a second mirror, from which it is reflected vertically downward to an objective of 150 feet (45.7 m)

[1] See p. 83.

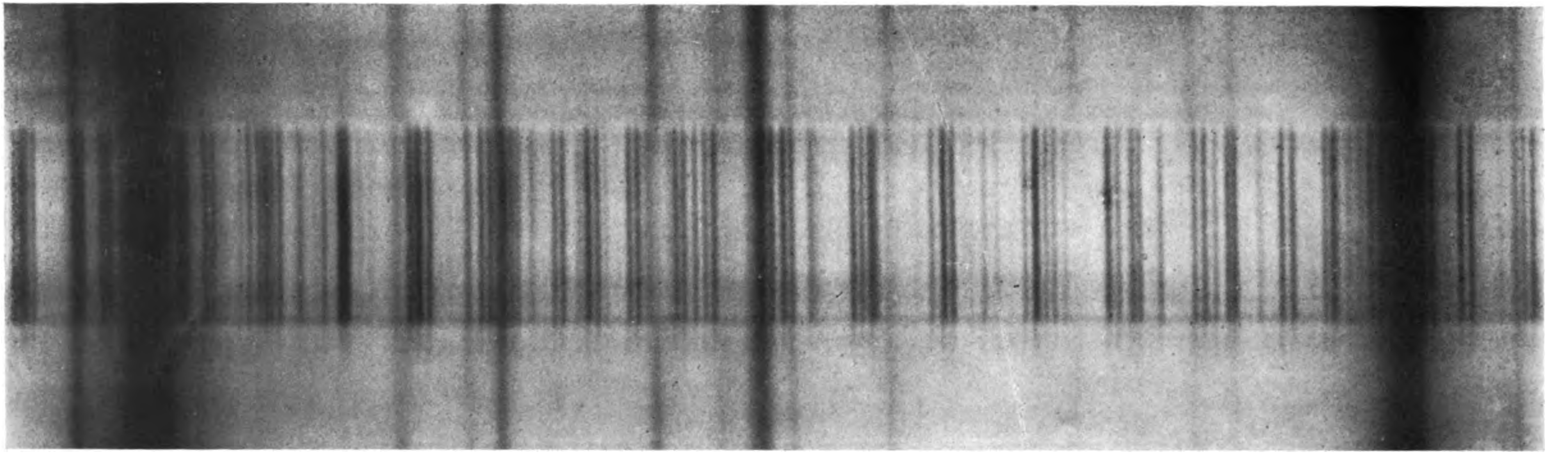
[2] Curves showing the theoretical displacements are given below (Figs. 2–7).

PLATE I

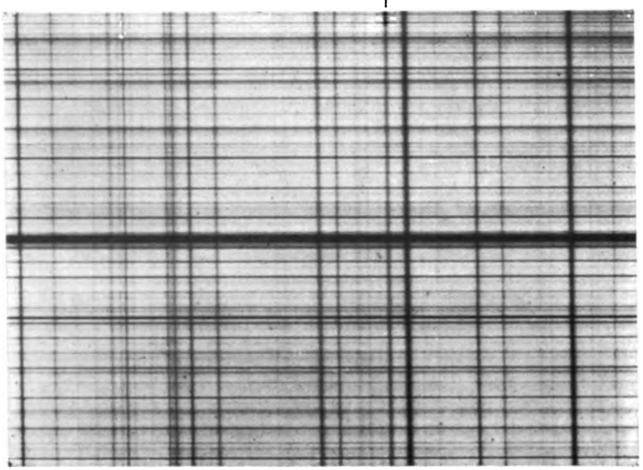


HEAD OF 75-FOOT SPECTROGRAPH OF 150-FOOT TOWER TELESCOPE SHOWING PLATE HOLDER, POLARIZING APPARATUS MOUNTED ABOVE SLIT, AND PARALLEL MOTION DEVICE USED FOR CENTERING SOLAR IMAGE

PLATE II



a



b

a. Solar spectrum and absorption spectrum of iodine vapor, region of the D lines of sodium, photographed in the third order with the 75-foot spectrograph. Slit-width, 0.127 mm. Central section, solar and iodine spectrum, exposure 35 min. Adjacent sections, solar spectrum, exposure 24 min. Scale: 1 Å = 27.8 mm. Enlargement 5.7 times.

b. Region of λ 5930 photographed in the third order with the 75-foot spectrograph showing the division of the spectrum into 2-mm strips by the compound quarter-wave plate. The heavy horizontal line marks the junction of two sections of the Nicol. The fifth strip below is the "marked strip" used for reference purposes. Scale: 1 Å = 4.90 mm.

focal length, which forms an image of the sun about 16½ inches (43 cm) in diameter in the laboratory at the base of the tower. The slit of the spectrograph, on which the image falls, is about 3 feet (0.9 m) above the floor (Plate I). After passing through the slit, the light descends to the collimating lens of 75 feet (22.9 m) focal length, mounted near the bottom of a well about 80 feet (24.4 m) deep, excavated in the earth beneath the tower. Below this lens, in a suitable mounting, is a large Michelson grating of very high resolving power (about 622 lines to the millimeter, available ruled surface 67×126 mm). After falling on the grating the light is returned through the collimating lens, which thus serves also as a camera-objective, and forms an image of the spectrum on a plate mounted close beside the slit of the spectrograph. In a single exposure a portion of the spectrum 40 inches (1 m) long can be photographed. A complete description of this instrument, which is also designed for use as a spectroheliograph, will soon be published.

The first photograph of the solar spectrum made with this spectrograph in January 1912 showed that a very high degree of precision might be expected in measurements of the positions of the solar lines. In the third-order spectrum, where much of the work described in this paper has been done, the scale at λ 5900 is 1 Ångström = 4.9 mm (Plate II, *b*). On this scale the distance between the D_1 and D_2 lines of the solar spectrum is 29 mm. An excellent test of the resolving power of the instrument is afforded by the exceedingly fine lines in the absorption spectrum of iodine, obtained by inserting a glass globe containing iodine vapor in the path of the solar beam[1] (Plate II, *a*). Near λ 5458 is a pair barely resolved photographically, having a measured separation of 0.025 Ångström. The theoretical resolution for this region, calculated from the formula

$$\frac{\delta\lambda}{\lambda}=\frac{1}{nm},$$

[1] The iodine absorption globe, for the use of which we are indebted to the suggestion of Wood, also provides a most convenient and accurate method of focusing the spectrograph. Settings made visually or photographically on the sharp iodine lines give the focus with much higher precision than would be attainable if the more diffuse lines of the solar spectrum were used.

is 0.023 Ångström. The width of the "normal slit," given by $\frac{f\lambda}{4D}$ where f is the focal length and D the aperture of the spectrograph, is 0.0288 mm. For the slit-width used in making the photograph (0.076 mm) Schuster gives a purity factor of 90 per cent.[1] Hence, on the above theory, the spectrograph should not separate lines in this region closer than 0.026 Ångström. In the fourth order fine iodine pairs near λ 5508 have separations of about 0.020 Ångström, but the solar lines are too diffuse for satisfactory measurement.

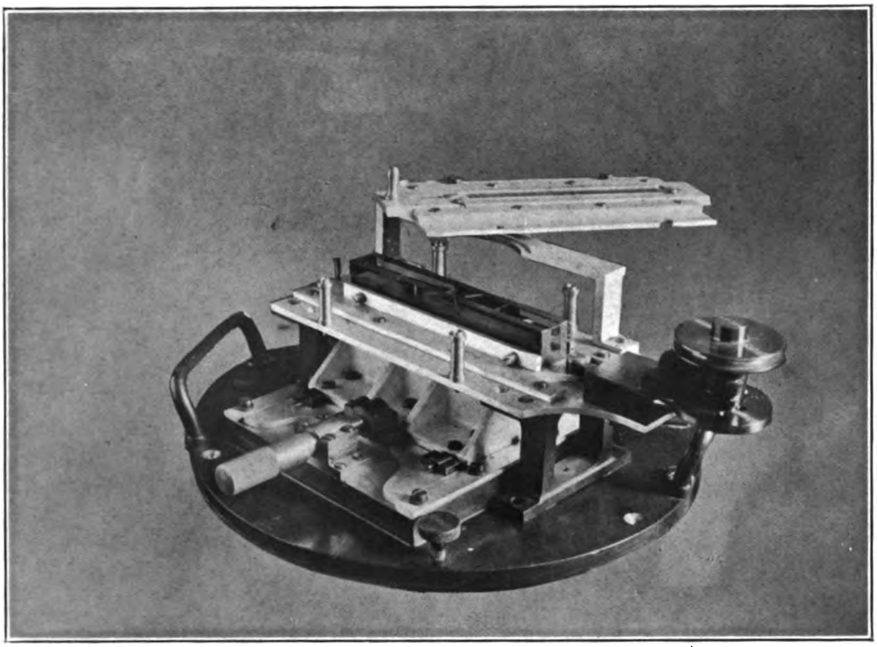
The polarizing apparatus, which forms so vital a part of the equipment required for the study of the sun's magnetic field, is illustrated in Plates III and IV. The general features of its design have been described above. The Nicol prism, 18 mm wide, built up by Werlein of four sections each 32.5 mm long so as to give a total length of 130 mm, is supported just above the slit of the spectrograph (Plate III, *a*). The junctions of the sections are necessarily marked in the spectrum by longitudinal bands (one of these appears in Plate II, *b*), but as a spectrum 90 mm wide can be photographed in a single exposure, the loss of measurable area caused by the composite structure of the Nicol is very small. If for any reason it becomes important to eliminate these longitudinal bands, this can be done by moving the Nicol prism back and forth, along the slit, during the exposure. Mechanism is provided to accomplish this, but for the purposes of the present investigation the Nicol is kept at rest, as it is important that the illumination of the grating should remain absolutely unchanged while each exposure is in progress.

For spectroscopic purposes, this long Nicol is even superior to a Nicol of the usual form, and of equal aperture (if such could be obtained). Its small thickness (8 mm) is a very decided advantage, and the impossibility of rotating it is easily overcome by the use of a half-wave plate, which can be mounted immediately above the Nicol (Plate III, *b*). Rotation of the half-wave plate through a given angle is equivalent to rotation of the Nicol through twice the angle, and the illumination of the grating is much less likely to be

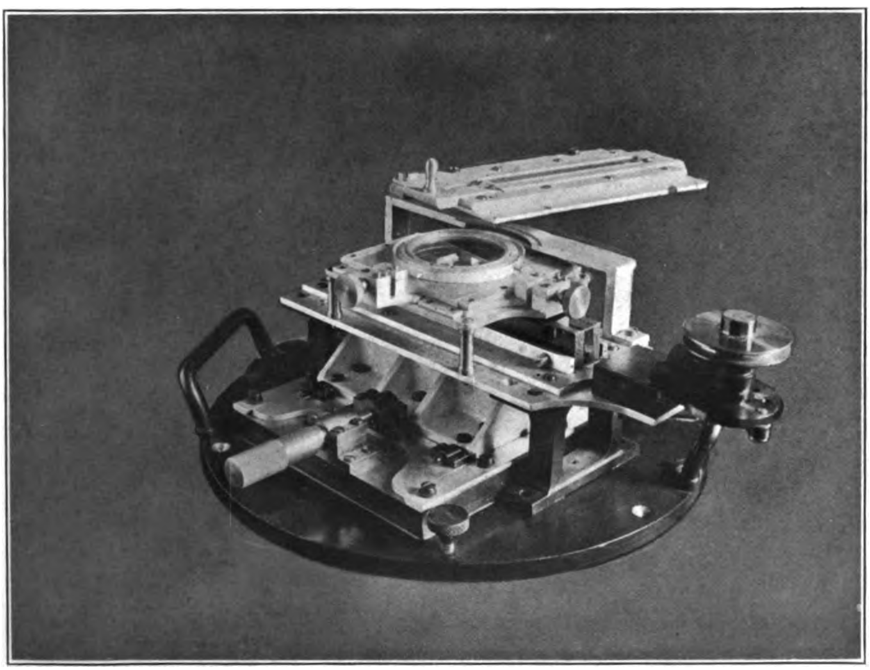
[1] *Astrophysical Journal*, **21**, 207, 1905.

PLATE III

a



b



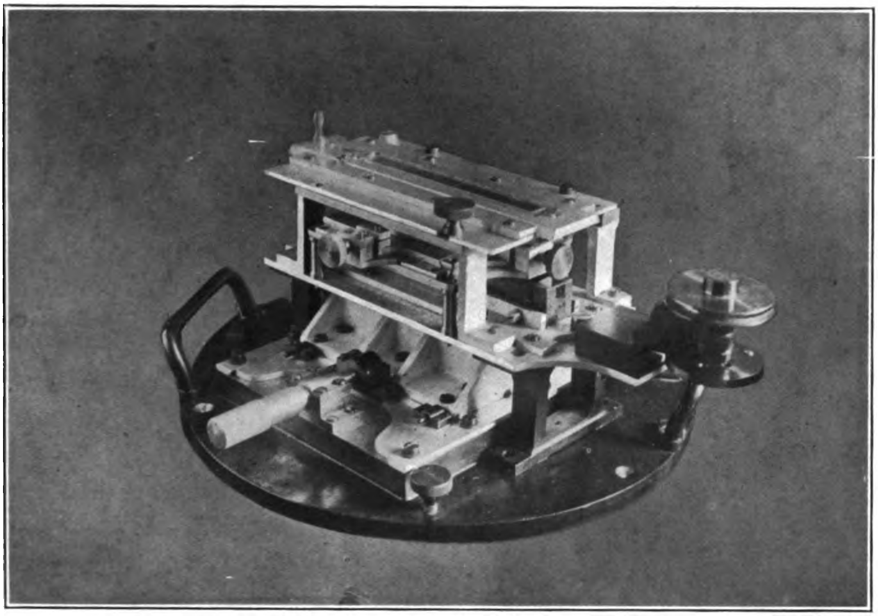
SLIT AND POLARIZING APPARATUS USED WITH THE 75-FOOT SPECTROGRAPH, COMPOUND QUARTER-WAVE PLATE SWUNG TO ONE SIDE

a. Showing the long Nicol prism mounted immediately above slit.

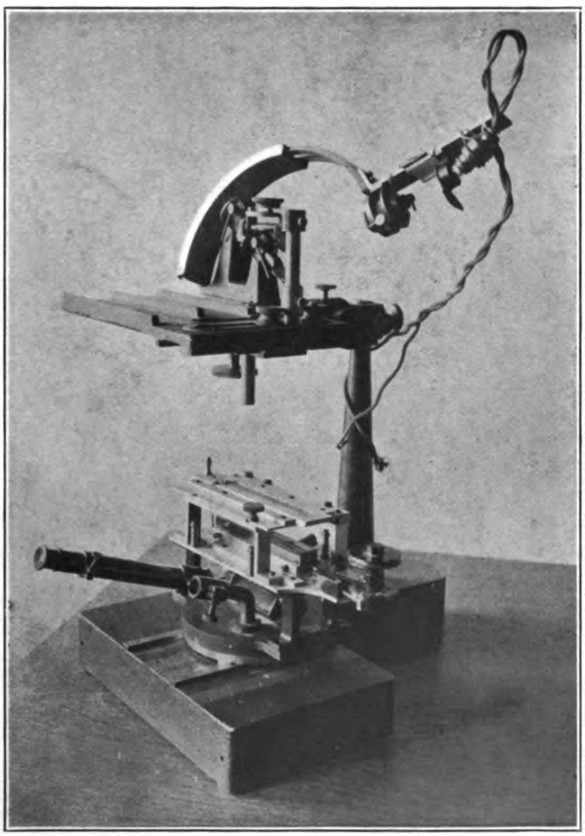
b. Showing the circular half-wave plate in position above the Nicol.

PLATE IV

a



b



a. Slit and polarizing apparatus of 75-foot spectrograph with compound quarter-wave plate in position for observation.

b. Polarimeter used for measuring the elliptical polarization produced by the coelostat mirror and second flat. The polarizing apparatus is mounted on the base of the instrument in position for tests.

affected when only the half-wave plate is turned. As this arrangement is designed mainly for use in the study of the magnetic fields of sun-spots, the aperture of the (circular) half-wave plate is only 50 mm, but a half-wave plate covering the whole length of the Nicol might easily be substituted for the smaller one. In place of the half-wave plate, or in conjunction with it, circular quarter-wave plates, or half-wave and quarter-wave plates divided along a diameter into halves with their principal sections intersecting at an angle of 90°, may be employed. Such combinations are required for certain studies of sun-spot phenomena, but are unnecessary in the present work. An important experiment with the aid of the single half-wave plate, however, is described on pp. 75–76.

The compound quarter-wave plate, used for the investigation of the sun's magnetic field in conjunction with the Nicol, usually without the interposition of the half-wave plate, is shown in position for use (Plate IV, *a*). The support in which it is mounted is so pivoted that it can be swung to one side (as in Plate III) when adjustments of the Nicol or half-wave plate are to be made. On account of the great focal length of the spectrograph, the distance of the compound quarter-wave plate from the Nicol (33 mm) is not sufficient to reduce materially the sharpness of the dividing lines between adjoining strips of spectra, as the photograph reproduced in Plate II, *b* indicates.[1]

The procedure followed in making photographs of spectra for the study of the sun's magnetic field is as follows: The Nicol prism and compound quarter-wave plate are mounted above the slit, and the grating is observed to see whether the illumination from the solar image is central and complete. A parallel-motion device for orientation and guiding, supported by a massive iron column rising from the spectrograph head, is then swung into position over the slit. This carries a glass disk, on which is engraved a circle, the axis of which is to coincide with the solar axis, while the equator

[1] Dust on the slit, or small defects in the quarter-wave plate or Nicol, produce horizontal lines in the spectrum, which may be confused with the lines corresponding to the edges of the quarter-wave strips. The latter are 2 mm apart in the reproduction, which is of the same size as the original negative.

and parallels provide a scale for the purpose of setting a certain "marked strip," near the center of the compound quarter-wave plate, at any desired latitude. The disk is first rotated in its support until the axis of the circle coincides accurately with the slit. The solar image is then moved in the direction of the diurnal motion by means of the electric quick motion of the coelostat,[1] and the spectrograph head is rotated until the sun's limb runs along the equator (drawn as a straight line at right angles to the axis) of the circle. The azimuth of the slit is given by a large position circle, reading by vernier to 1′, engraved on the circumference of the spectrograph head. The tabulated position angle of the sun's axis for the date of observation is then the angle through which the spectrograph head must be turned in order to make the slit parallel to the sun's axis. The average error of orientation by this method does not exceed 15′, and could easily be made less, if this were necessary.

The grating support at the bottom of the well is not connected with the spectrograph head, but mounted on an independent support, which is rotated in azimuth by means of an electric motor until a telescope on the spectrograph head indicates the correct circle reading. The lines of the grating are then parallel to the slit. The grating itself is next rotated by another electric motor, about an axis parallel to the rulings, until the desired part of the spectrum comes into view. For most of the work described in this paper the region of the second or third order including the lines λ 5812, λ 5828, and λ 5930 was the one photographed. The overlapping spectra are cut out by a screen which transmits the region less refrangible than λ 5800. If the illumination of the grating is still perfect, and the focal setting of the collimator-camera objective (obtained with the greatest precision by the aid of the iodine absorption spectrum) is adjusted (by electric motor), the spectrograph is ready for the exposure as soon as the plates are inserted. Seed "23" or Seed "Process" plates, of very fine grain, sensitized for the red by Wallace's method, are used for the region below λ 5800. It now remains to set the solar image in the proper position on the slit.

[1] Careful tests, made from time to time, show that this direction corresponds closely with that obtained by allowing the image to drift.

The orientation device is moved until the shadow of a wire, crossing the axis of the circle at the desired latitude, falls on the "marked strip" of the quarter-wave plate. This is easily accomplished without destroying the coincidence of the axis with the slit, by the aid of the parallel-motion support. It is then only necessary to move the solar image, with the electric motions of the coelostat and second mirror, until it lies centrally within the circle, and to keep it there throughout the exposure. This amounts to about 20 minutes at λ 5900 in the third order, with a Seed "23" plate. The stability of the spectrograph, the constancy of temperature at the grating level, and the optical perfection of the air within the well are sufficiently indicated by the high resolution of the iodine absorption spectrum (Plate II, *a*) photographed in the third order on a "Process" plate with an exposure of 35 minutes.

At λ 5900 in the third order the effective aperture of the spectrograph is 126 mm, while its focal length is 22.9 m. Hence the ratio is 1/181. In the tower telescope two visual objectives, each of 12 inches (30.5 cm) aperture, but of different focal lengths, have been used to form the solar image on the slit. For the first of these the focal length is 60 feet (18.3 m), and the ratio 1/60. The corresponding diameter of the solar image is about 17 cm. The second objective has a focal length of nearly 150 feet (45.7 m), and gives a solar image about 43 cm in diameter. The ratio of 1/150 indicates that the circle of light from a short slit is 152 mm in diameter on the spectrograph objective (taking no account of diffraction), and hence more than sufficient to fill the grating. An objective of 30 feet (9.1 m) focal length was also used for a time, but the solar image was too small for satisfactory measures in the higher latitudes.

It will be observed that the greatest source of error in the comparison of the spectra of different light-sources, namely the displacement of lines caused by differences in the illumination of the grating, is not to be feared in the present investigation. Nevertheless, although the method is purely differential, the adjustments were made with the same care needed in other classes of work. Various means of checking the results are described in the discussion of possible sources of error (p. 63). The most valuable of these

is the practice of making duplicate exposures with the compound quarter-wave plate in the normal (+) and inverted (−) positions which should give displacements of opposite sign if they are caused by a magnetic field (p. 77).

The preliminary selection of solar lines for measurement was determined by three principal considerations:

1. The less refrangible region of the spectrum is advantageous because, on the average, the separation of the components of lines by a magnetic field varies directly as the square of the wave-length.

2. However, too great a wave-length is undesirable, since the average sharpness of the solar lines decreases as the wave-length increases.

TABLE I

MEASURES BY MISS LASBY OF PLATE T′3, LAT. S. 50°
(January 5, 1912, 3^h48^m–4^h25^m, P.S.T.)

λ	Origin	Intensity	$\frac{\Delta\lambda}{\lambda^2}$	Displacement
				mm
5884.028.......	*Fe*	4	1.259	+0.002
5884.120.......	*A*	5	.....	+ .001
5892.608.......	*A*	3	.....	.000
5892.920.......	*Fe*	∞	.....	− .008
5893.097.......	*Ni*	4	.....	− .002
5893.268.......	*A*	0	.....	.000
5899.215.......	*A*	2	.....	− .001
5899.518.......	*Ti*	1	1.885	− .002
5900.135.......	*A*	2	.....	− .001
5915.840.......	*A*	1	.....	+ .001
5916.475.......	*Fe*	3	.....	− .005
5916.800.......	*A*	0	.....	− .001
5918.773.......	*Ti*	0	2.518	+ .001
5928.013.......	*Fe*	2	.....	− .002
5928.510.......	*A*	2	.....	+ .001
5929.898.......	*Fe*	2	.....	− .013
5930.406.......	*Fe*	6	1.669	+ .001
5941.845.......	*A*	2	.....	.000
5941.985.......	*Ti*	∞	2.563	+ .001
5942.789.......	*A*	3	.....	.000
5952.943.......	*Fe*	4	.....	+ .002
5953.386.......	*Ti*	1	1.798	.000
5975.330.......	*A*	1	.....	+ .001
5977.007.......	*Fe*	4	1.777	−0.001

3. The large separations $\left(\frac{\Delta\lambda}{\lambda^2}\right)$ observed in the laboratory for certain spark lines indicated that these should be tried if sharp enough in the sun. However, it might easily happen that other

solar lines, too weak in laboratory sources to give the Zeeman effect, would prove to have larger displacements.

These considerations led to the selection of the region λ 5800–λ 6000, in which the lines shown in Table I are found.

The tabulated values give the double displacement, corresponding to the separation of the *n*-components of a Zeeman triplet.[1]

The measured displacements of most of the solar lines in Table I are too small to be regarded as genuine. But the iron[2] line λ 5929.898, giving a displacement of −0.013 mm (corresponding to nearly 0.003 Ångström), is apparently in a different class. An examination with a hand magnifier of the less refrangible region of Plate T′4 (Lat. S. 50°, January 6, 1912, 9^h0^m–9^h27^m P.S.T.) showed three other lines having clearly visible displacements. As measured by Miss Lasby, the displacements of these lines on two adjoining sets of strips (four strips in each set) were as follows:

TABLE II

λ	Origin	Intensity	First Set	Second Set
			mm	mm
5812.139.......	*Fe*	0	−0.012	−0.013
5828.097.......	..	0	−0.011	−0.014
5831.821.......	*Ni*	1	−0.007	−0.006

For the preliminary investigation it was thought best to obtain a large number of measures of a few lines, rather than a smaller number of measures of many lines. If the results were found to indicate beyond reasonable doubt that the displacements should be attributed to the Zeeman effect, the inclusion of other lines would naturally follow. The three lines showing the largest displacements, λ 5812.139 (*Fe*, 0), λ 5828.097 (—, 0), and λ 5929.898 (*Fe*, 2) were accordingly selected for systematic investigation at various latitudes in both hemispheres of the sun.

[1] This double displacement, however, does not give a direct measure of the strength of the solar field, owing to the increasing ellipticity toward the poles and equator of the light of the components, which involves less and less complete extinction by the quarter-wave plate and Nicol. See p. 91.

[2] Recent results indicate that this line may not be due to iron, though it is so identified by Rowland.

RECORD OF OBSERVATIONS

Two hundred and eighty-eight photographs of spectra have been made for the purposes of this investigation, but only those which have been measured and discussed are included in the present record. A considerable number of plates have been rejected on account of photographic defects. From the earlier measures it was found that there is a close connection between discordances in the measured displacements and what ordinarily would be regarded as only small deviations from high technical quality in the photographs. Thereafter each plate was carefully scrutinized, and if it presented any imperfection it was rejected without measurement. This exclusion was even more rigorously exercised with the later series than with the earlier, and doubtless accounts in part for a considerable gain in precision.

The first observations were made in January 1912, immediately after the completion of the 75-foot (22.9 m) spectrograph. As already stated, negative results had been obtained in the previous autumn with the 60-foot tower telescope and 30-foot (9.1 m) spectrograph, and as the long-focus objective of the new tower had not been completed, the 12-inch (30.5 cm) objective of 60 feet (18.3 m) focal length was temporarily transferred from the old to the new tower, and used for the first series of observations. This extended from January 6 to February 29, 1912.

Many photographs were made during March and April of the λ 5930 region in the second order and in the blue of the third order, where the line λ 4446.566 had seemed to show displacements. The objective of 30 feet focal length was used to form the solar image on the slit, but the rapid change of latitude in the higher zones rendered so small an image unsuitable. As the measured displacements of λ 5930 on these plates proved to be much smaller than in the case of the third-order plates, another series of observations in the second order (called here the second series) was begun on May 30 with the objective of 150 feet focal length, which had just been received from Brashear. At this period the temperature of the coelostat and second mirrors was not controlled, and the solar image showed large changes of focus and marked astigmatism. On July 17 the lower section of the spectrograph was raised from the

bottom of the well to the 30-foot level, so as to permit a collimator-camera objective of 30 feet focal length to be used for photographing the spectrum of the chromosphere. As the difficulty with astigmatism continued, a steady flow of water from a large tank was maintained in water jackets surrounding the sides and backs of the two mirrors. This completely cured the astigmatism and greatly reduced the range of focal length. On November 21, after the lower section of the spectrograph had been replaced at the bottom of the well, observations of the sun's field were resumed with the spectrograph of 75 feet focal length (third order) and the 43-cm solar image.

From November 21 to 29 the observations, with few exceptions, were on λ 5929.898. These are designated as the third series. The fourth series includes the results for $\lambda\lambda$ 5812.139 and 5828.097 obtained between the dates January 29 and February 18, 1913. The photographs of the second, third, and fourth series were made in pairs (quarter-wave plate in the normal and inverted positions) to provide an additional test of the magnetic nature of the displacements.

The following data are recorded in the observing book: plate number, date, hour, and minute of beginning and end of exposure, hemisphere (northern or southern), slit-width, order, region and focus of spectrum, focus of solar image, reading of spectrograph position circle, position of plate (which can be moved parallel to itself, so as to allow two exposures of a spectrum 90 mm wide to be made on one plate), inclination of plate, Nicol and quarter-wave plate used, position of quarter-wave plate (normal or inverted), distance of "marked strip" from center of sun, position angle of half-wave plate (if used), ray filter and kind of plate used, quality of seeing, telescope objective used, spectrograph objective used, grating used, temperature of well, temperature of observing room, and position of coelostat. During morning observations the coelostat stands at 600 mm east, in the afternoon at 600 mm west. Its position in a north-and-south direction with reference to the (fixed) second mirror varies with the declination of the sun. Both readings should be known, as they affect the orientation of the spectrograph, and must agree with the settings of the small

polarimeter (p. 70) used to reproduce and measure the polarization phenomena of the tower telescope mirrors corresponding to a given declination and hour angle of the sun.

For the present investigation, however, only a part of these data is required. The details of importance for the four series of observations here discussed are collected in Table III, pp. 46–53. The latitudes for which the displacements have been measured were found by means of a scale so graduated as to read directly the required values. The recorded latitude of the "marked strip" afforded the necessary data for the adjustment of the zero point of the scale. The value of λ in the fifth column is the wave-length for which the quarter-wave plate used is corrected. The signs in the sixth column refer to the position of the plate, $+$ indicating the normal and $-$ the inverted position. The significance of the data for the half-wave plate in the last column is explained in the discussion of the observations (p. 76). For the first two series the value of the slit-width was usually 0.004 in. (0.102 mm); for the last two, 0.005 in. (0.127 mm).

MEASUREMENT AND REDUCTION OF THE PHOTOGRAPHS

FIRST SERIES

As already explained, the sections of the compound quarter-wave plate, each 2 mm wide, divide the spectrum longitudinally into strips of the same width (Plate II, b). If the red and violet components of a solar line are reduced in intensity or are cut off on successive strips, relative displacements of the lines must result, which are measured in the following manner. Four strips are used in each set of measures and four settings are made, in both the direct and reversed positions of the plate, on the solar line in each strip.[1] If we call the mean settings for successive strips a, b, c, d, the results are combined as follows, to eliminate any error due to lack of parallelism of the micrometer wire and the solar line:

$$\Delta=\frac{1}{2}\left\{\left(\frac{a+c}{2}-b\right)-\left(\frac{b+d}{2}-c\right)\right\}.$$

[1] In the earlier work all of the strips except the one being measured were covered, but later this was found to be unnecessary.

The position of the solar line on a certain strip (the "marked strip") of the quarter-wave plate is taken as the zero of reference. Displacements of the line on the adjoining strips are called positive when toward the red, and negative when toward the violet. When the line of sight is parallel to the lines of force, the strips adjoining the "marked strip" used in combination with the Nicol transmit light from the left-handed circularly polarized component. When inclined to the lines of force, the vibrations received from the outer components will be elliptical, and a part of the right-handed component will also be transmitted; but the amount will always be less than that from the left-handed component. A positive displacement, therefore, means that the light of the red component of the solar line is circularly or elliptically polarized in the left-handed direction.

As a check on the results, at least one atmospheric line was measured on most of the plates of the first series; such a line, being produced in the earth's atmosphere, should of course show no displacements. At present, atmospheric lines are measured only occasionally, as they are invariably found to give no shifts exceeding the errors of measurement.

Miss Lasby's measures of Plates 3 and 4 have already been given (Tables I and II). These were made by the above method on a Toepfer measuring machine having a 150-mm screw with a pitch of 0.5 mm. An investigation of this screw indicates very small periodic errors, amounting at the maximum to 0.0003 mm, and therefore much below the errors of setting. The errors of run are small, but in any case they would not affect small differential measures of this nature. A Gaertner machine, used for a few of the measures, has periodic errors as great as 0.002 mm, but as this corresponds to a half-revolution of the screw (0.250 mm), while the maximum displacements of the solar lines in the present work never exceed 0.020 mm, the resulting error of 0.00015 mm is quite inappreciable.

An examination of Tables I and II certainly suggests that the measured displacements of at least three of the solar lines are genuine, and not due to any fault of the spectrograph or the polarizing apparatus. A valuable check is afforded by the atmospheric

TABLE III

Record of Observations

FIRST SERIES—THIRD-ORDER SPECTRUM, λλ 5812, 5828, AND 5930

FOCAL LENGTH OF TELESCOPE OBJECTIVE 60 FEET

Plate No.	Date	P.S.T.	Latitudes Measured	Quarter-Wave Plate λ	Quarter-Wave Plate Pos.	Observer	Remarks
	1912						
T′ 4	Jan. 26	$9^h\ 0^m$ — $9^h 27^m$	S 43, 50, 60	6300	+	H and E	
10	30	8 50 — 9 15	N 52, 40	6300	+	H and E	
11	30	9 32 — 9 47	S 40, 52	6300	+	H and E	
14	31	9 55 —10 30	S 46, 55, 65	6300	+	H and E	
15	31	11 8 —11 28	0; S 6, 12	6300	+	H and E	
17	31	2 43 — 3 8	N 40, 34, 28	6300	+	H and E	
18	31	3 29 — 3 59	S 45, 53, 63	6300	+	H and E	
19	31	4 14 — 4 44	S 7, 12, 18	6300	+	H and E	
21	Feb. 1	....	N 6; S 2, 12, 20, 35	6300	+	H and E	
23	8	3 59 — 4 20	N 60, 43, 30	6300	+	H and E	
24	9	11 31 —11 51	N 45, 38, 28	6300	+	H and E	
25	9	12 5 —12 26	N 60, 43, 33	6300	+	H and E	
26	16	3 14 — 3 49	S 47, 57, 74	6300	+	H and E	λ/2 Plate at 0°
27	16	4 8 — 4 43	S 46, 56	6300	+	H and E	λ/2 Plate at −45
28	16	4 53 — 5 23	S 46, 55	6300	+	H and E	λ/2 Plate at −22½
29	17	10 37 —11 4	N 44, 37, 29	6300	+	H and E	λ/2 Plate at 0
30	17	11 22 —11 47	N 37, 30	6300	+	H and E	λ/2 Plate at −45
31	17	11 59 —12 24	N 42, 32	6300	+	H and E	λ/2 Plate at −22½
32	19	2 5 — 2 35	N 42	6300	+	H and E	λ/2 Plate at 0
33	19	3 3 — 3 33	N 42	6300	+	H and E	λ/2 Plate at −22½
34	19	3 56 — 4 26	N 40	6300	+	H and E	λ/2 Plate at −45
35	20	2 39 — 3 44	N 45	6300	+	H and E	λ/2 Plate at ±180
36	20	4 0 — 4 45	N 50	6300	+	H and E	λ/2 Plate at −135
37	21	9 33 —10 8	N 50, 40	6300	+	H and E	λ/2 Plate at +135
39	21	1 53 — 2 43	N 50, 38	6300	+	H and E	λ/2 Plate at ±180

TABLE III—*Continued*

T′ 40......	Feb. 21	3 14 — 3 59	N 55, 45, 39	6300	+	H and E	
41......	21	4 20 — 5 7	S 33, 43	6300	+	H and E	
42......	22	2 26 — 3 11	N 58, 45, 35, 26, 18	6300	+	H and E	
43......	22	3 52 — 4 52	S 36, 45, 60	6300	+	H and E	
44......	25	3 44 — 4 20	N 55, 45, 35, 25, 16, 8, 0	6300	+	H and E	
45......	25	4 49 — 5 56	S 2, 10, 17, 26, 35	6300	+	H and E	
46......	26	9 42 —10 17	N 54, 42, 32, 22	6300	+	H and E	
48......	27	9 27 — 9 49	S 27, 36, 47, 60	6300	+	H and E	
49......	27	10 23 —	N 45, 37, 27, 18, 10, 3; S 5	6300	+	H and E	
50......	28	9 7 — 9 32	S 10, 17, 26, 36, 45	6300	−	H and E	
51......	28	9 46 —10 11	N 28, 19, 12, 5	6300	−	H and E	
55......	29	9 56 —10 26	N 58, 45, 35, 25, 16, 8	6300	+	E	

SECOND SERIES—SECOND-ORDER SPECTRUM, λλ 5812, 5828, AND 5930
FOCAL LENGTH OF TELESCOPE OBJECTIVE 150 FEET

125*a*.....	June 3	1 27 — 1 47	N 60, 37	5650	+	E	
125*b*.....	3	1 49 — 2 9	N 60, 37	5650	−	E	
126*a*.....	3	2 12 — 2 32	N 60, 37	5650	−	E	
126*b*.....	3	2 34 — 2 55	N 60, 37	5650	+	E	
127*a*.....	3	3 0 — 3 20	N 58, 38	5650	+	E	
127*b*.....	3	3 21 — 3 42	N 58, 38	5650	+	E	
129*a*.....	4	9 35 — 9 53	N 58, 38	5650	−	E	
129*b*.....	4	9 55 —10 15	N 58, 38	5650	+	E	
130*a*.....	4	10 23 —10 43	N 56, 38	5650	+	E	
130*b*.....	4	10 45 —11 5	N 56, 38	5650	−	E	

TABLE III—*Continued*

Plate No.	Date	P.S.T.	Latitudes Measured	Quarter-Wave Plate		Observer	Remarks
				λ	Pos.		
T′ 131*a*.....	1912 June 4	11ʰ11ᵐ —11ʰ29ᵐ	N 55, 34	5650	−	E	
131*b*.....	4	11 31 —11 49	N 55, 34	5650	+	E	
133*a*.....	4	2 9 — 2 29	S 34, 55	5650	−	E	
133*b*.....	4	2 37 — 2 57	S 34, 55	5650	+	E	
134*a*.....	4	3 3 — 3 25	S 34, 55	5650	+	E	
134*b*.....	4	3 25 — 3 48	S 34, 55	5650	+		
135*a*.....	11	2 59 — 3 39	S 32, 53	5650	+	E	
135*b*.....	11	3 52 — 4 40	S 32, 53	5650	−	E	
137*a*.....	15	4 31 — 4 52	N 62, 36	5650	−	K	
137*b*.....	15	4 55 — 5 16	N 62, 36	5650	+	K	
142*a*.....	17	10 33 —11 3	S 35, 62	5650	+	K	Spot at east limb
142*b*.....	17	11 6 —11 36	S 35, 62	5650	−	K	Small spot at S 10° W 4°
143*a*.....	18	8 14 — 8 39	N 63, 38	5650	−	K	Small spot has disappeared
143*b*.....	18	8 42 — 9 7	N 63, 38	5650	+	K	
144*a*.....	18	9 17 — 9 37	S 41, 60	5650	+	K	
144*b*.....	18	9 42 —10 2	S 41, 60	5650	−	K	
145*a*.....	18	10 15 —10 35	S 2	5650	−	K	
145*b*.....	18	10 38 —10 58	S 2	5650	+	K	

TABLE III—*Continued*

T′ 146*a*.....	June 19	1 52 — 2 15	N 43	5650	+	K	
146*b*.....	19	2 18 — 2 43	N 43	5650	−	K	
147*a*.....	19	2 53 — 3 11	S 31, 53	5650	−	K	
147*b*.....	19	3 14 — 3 32	S 31, 53	5650	+	K	
148*a*.....	19	3 45 — 4 7	N 10; S 5	5650	+	K	Spot at S 7° E 38°
148*b*.....	19	4 12 — 4 36	N 10; S 5	5650	−	K	
149*a*.....	20	9 21 — 9 56	N 53, 42	5650	+	K	Spot at S 7° E 31°. Interrupted for 10^m by failure of coelostat
149*b*.....	20	10 5 —10 30	N 53, 43	5650	−	K	
153*a*.....	21	2 12 — 3 6	N 10; S 5	5650	+	K	Spot at E 14°
153*b*.....	21	3 8 — 4 15	N 10; S 5	5650	−	K	
154*a*.....	25	8 22 — 8 52	N 60, 35	5650	−	E	
154*b*.....	25	8 55 — 9 30	N 60, 35	5650	+	E	
155*a*.....	25	9 40 —10 5	N 11; S 4	5650	+	E	
155*b*.....	25	10 9 —10 33	N 11; S 4	5650	−	E	
156*a*.....	25	10 42 —11 7	S 31, 51	5650	−	E	
156*b*.....	25	11 9 —11 33	S 31, 51	5650	+	E	
159*a*.....	26	10 30 —10 50	N 7; S 4	5650	−	E	
159*b*.....	26	10 51 —11 11	N 7; S 4	5650	+	E	
160*a*.....	26	11 17 —11 38	S 41	5650	+	E	
160*b*.....	26	11 39 —11 60	S 41	5650	..	E	

TABLE III—*Continued*

THIRD SERIES—THIRD-ORDER SPECTRUM, λ 5930
FOCAL LENGTH OF TELESCOPE OBJECTIVE 150 FEET

Plate No.	Date	P.S.T.	Latitudes Measured	Quarter-Wave Plate λ	Quarter-Wave Plate Pos.	Observer	Remarks
T′ 181a.....	1912 Nov. 22	8^h47^m — 9^h33^m	N 46, 42, 37	5650	−	H and E	
181b.....	22	9 37 —10 22	N 62, 53, 46, 42	5650	+	H and E	
184a.....	23	8 5 — 8 45	N 60, 53, 45	5650	+	H and E	
184b.....	23	8 51 — 9 33	N 60, 53, 45	5650	−	H and E	
185a.....	23	10 28 —11 8	S 34, 38, 47, 52	5650	−	E	
185b.....	23	11 10 —11 50	S 34, 38, 47, 52	5650	+	E	
187a.....	24	8 8 — 9 0	S 33	5650	−	E	
192b.....	25	2 0 — 3 0	N 43, 39	5650	−	E	
193a.....	26	8 50 — 9 55	N 43, 39	5650	−	E	
193b.....	26	9 57 —10 57	N 60, 43, 39	5650	+	E	
194a.....	26	11 6 —12 3	S 36, 42	5650	+	E	
196a.....	27	11 2 —12 2	S 33, 38, 47, 52	5650	+	E	
196b.....	27	1 22 — 2 32	S 33, 47, 52	5650	−	E	
200a.....	29	10 17 —10 57	N 59, 52, 43, 41, 36, 32	5650	−	E	
200b.....	29	11 0 —11 40	N 58, 53, 48, 43, 35	5650	+	E	
203a.....	Dec. 5	1 39 — 2 27	N 11, 7, 2; S 2, 6	6300	+	E	
203b.....	5	2 28 — 3 30	N 11, 7, 2; S 2, 6	6300	−	E	
211a.....	14	10 7 —11 4	S 33, 37, 43, 48	6300	−	E	

TABLE III—*Continued*

T′ 212*a*.....	Dec. 18	8 41 — 9 46	S 33, 37, 43, 47, 53	6300	+	E	
212*b*.....	18	9 50 —10 51	N 59, 54, 46, 42, 37	6300	+	E	
217*a*.....	20	8 25 — 9 37	N 51, 47	6300	+	E	
217*b*.....	20	9 39 —10 43	N 51, 47	6300	−	E	
220*a*.....	21	8 32 — 9 38	S 33, 45, 50, 53	6300	+	E	
220*b*.....	21	9 40 —10 43	S 33, 38, 45, 50, 53	6300	−	E	
223*a*.....	22	8 25 — 9 36	N 54, 45, 41, 36	6300	+	E	
223*b*.....	22	9 37 —10 42	N 59, 54, 45, 41, 36	6300	+	E	
226*a*.....	23	8 21 — 9 30	S 38, 45, 49, 55	6300	+	E	
226*b*.....	23	9 31 —10 36	S 38, 45, 49, 55	6300	−	E	
230*a*.....	28	9 24 —10 30	N 66, 59, 53, 49, 45, 39	6300	+	E	
230*b*.....	28	10 32 —11 35	N 66, 59, 53, 49, 45, 41	6300	−	E	
232*a*.....	29	8 47 — 9 49	S 37, 39, 47, 52, 57	6300	−	E	
232*b*.....	29	9 50 —10 50	S 37, 39, 47, 52, 57	6300	+	E	
233*a*.....	29	10 52 —11 57	S 37, 39, 47, 52, 57	6300	+	E	
233*b*.....	29	1 5 — 2 14	N 56, 52, 43, 39, 35	6300	+	E	

TABLE III—*Continued*

FOURTH SERIES—THIRD-ORDER SPECTRUM, λλ 5812 AND 5828

FOCAL LENGTH OF TELESCOPE OBJECTIVE 150 FEET

Plate No.	Date	P.S.T.	Latitudes Measured	Quarter-Wave Plate λ	Quarter-Wave Plate Pos.	Observer	Remarks
T′ 255*a*.....	1913 Jan. 29	10^h56^m —11^h24^m	S 49, 52, 60, 66, 73	5650	−	E	
255*b*.....	29	11 27 —11 55	S 47, 52, 60, 66, 72, 79	5650	+	E	
258*a*.....	30	8 34 — 8 58	S 42, 46, 52, 56, 63	5650	+	E	
258*b*.....	30	9 0 — 9 22	S 42, 46, 52, 56, 63	5650	−	E	
261*a*.....	30	11 1 —11 22	S 42, 44, 52, 57, 62	5650	−	E	
261*b*.....	30	11 24 —11 45	S 39, 44, 52, 57, 62, 68	5650	+	E	
264*a*.....	31	8 33 — 9 19	S 47, 51, 60, 66, 73, 79	5650	+	E	
264*b*.....	31	9 20 —10 3	S 47, 51, 60, 66, 73, 79	5650	−	E	
265*a*.....	31	10 8 —11 0	S 48, 51, 59, 65, 72, 82	5650	−	E	
265*b*.....	31	11 1 —11 54	S 47, 51, 59, 65, 72, 82	5650	+	E	
271*b*.....	Feb. 9	10 54 —11 19	N 64, 58, 47, 42, 37, 35	5650	+	E	
272*a*.....	10	8 43 — 9 23	N 68, 58, 47, 41, 36	5650	+	E	
273*b*.....	10	10 50 —11 29	N 68, 60, 50, 44, 40, 36	5650	+	E	
274*a*.....	10	12 40 — 1 26	N 70, 63, 50, 45, 40, 36	5650	+	W	
275*a*.....	10	2 20 — 2 41	N 27, 20, 16, 12	5650	−	W	
275*b*.....	10	2 42 — 3 4	N 30, 26, 20, 16, 12, 9	5650	+		
276*a*.....	11	8 30 — 9 12	N 71, 59, 49, 44, 38	5650	+	E	

TABLE III—*Continued*

T′ 279*b*.....	Feb. 13	11 10 —11 59	S 47, 51, 59, 65, 72, 78	5650	+	E	
280*a*.....	13	1 25 — 1 45	S 24, 28, 34, 37	5650	+	W	
283*a*.....	14	2 53 — 3 17	S 19, 22, 28, 31, 35, 39	6300	+	W	λ/4 for λ 6300 has been remounted
283*b*.....	14	3 18 — 4 00	S 37, 41, 48, 51, 60, 64	6300	+	W	
288*a*.....	18	9 10 — 9 23	N 21, 17, 14, 10, 5, 1	6300	+	E	
288*b*.....	18	9 36 — 9 57	N 21, 17, 14, 10, 5, 1	6300	+	E	
290*a*.....	18	10 55 —11 15	S 0, 3, 7, 12, 17, 21	6300	−	E	
290*b*.....	18	11 15 —11 35	S 0, 3, 7, 12, 17, 21	6300	−	E	

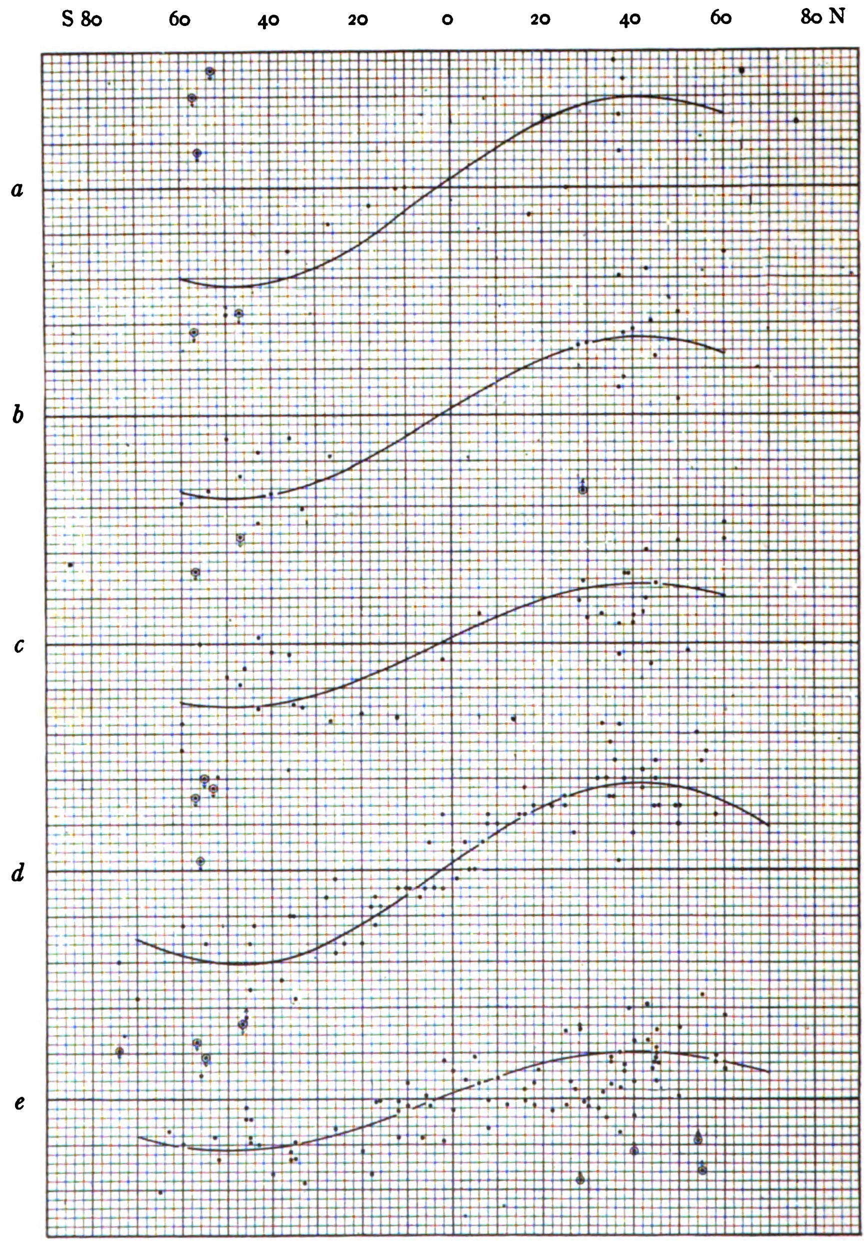


FIG. 2.—Displacements for the first series

a, Mean displacements for λλ 5812 and 5828 measured by Miss Lasby; *b*, λ 5812 measured by Mr. Van Maanen; *c*, λ 5828 measured by Mr. Van Maanen; *d*, λ 5930 measured by Miss Lasby; *e*, λ 5930 measured by Mr. Van Maanen.

Vertical scale: 1 division = 0.001 mm.

lines, which show no shifts greater than the errors of setting. The work of measuring the three lines having the largest displacements on Plates 3 and 4 was accordingly continued by Miss Lasby, with the results collected in Tables IV and VI, which give the values of the relative displacements, expressed in thousandths of a millimeter and arranged in order of decreasing latitude. In general, as is indicated by the numerical values of the displacements and by Fig. 2, *a* and *d*, Miss Lasby's measures show positive displacements, gradually decreasing from a maximum of about 0.010 mm (0.002 Ångström) for points in middle northern latitudes (N. 45°)

TABLE IV

FIRST SERIES—$\lambda\lambda$ 5812.139 AND 5828.097 IN THIRD-ORDER SPECTRUM
Measures by Miss Lasby

LAT.	Δ		MEAN Δ	PLATE NO.
	λ 5812	λ 5828		
N 38°	+12	+12	+12	25
37	+ 8	+ 8	+ 8	29
37	+ 6	+ 3	+ 4	30
36	+13	+14	+14	23
N 33	+17	+16	+16	24
S 10	− 1	+ 2	0	48
12	− 1	0	0	19
18	− 2	− 1	− 2	48
27	− 4	− 4	− 4	48
36	− 6	− 8	− 7	48
50	−13	−14	−14	4
53	(+12)	(+14)	(+13)	18
56	(+ 4)	(+ 4)	(+ 4)	27
S 57	(+ 8)	(+12)	(+10)	26

to zero near the equator, and increasing again, with reversed sign, toward a similar maximum in middle southern latitudes (±S. 45°). There are a few discrepancies in sign, but most of the measures are remarkably consistent. Every precaution was taken to prevent bias on the part of the observer, who did not know the latitude or hemisphere of any plate.

But in spite of the excellent internal agreement of the measures, the fact that the lines in Table I having the largest values of $\Delta\lambda/\lambda^2$ showed no appreciable displacement raised a question as to the possibility that the observed shifts of λ 5812, λ 5828, and λ 5930 might be due to some obscure source of error. This could hardly lie in the measures themselves, as Miss Lasby had acquired much

experience in the measurement of photographs of spectra showing the solar rotation, and in other investigations of an equally exacting nature. The high precision attained in this work of Mr. Adams and Miss Lasby is shown by the published results,[1] which have been confirmed by the interferometer measures of Perot. In the present case a number of check measures were kindly made by Mr. Adams.

TABLE V

FIRST SERIES—λλ 5812.139 AND 5828.097 IN THIRD-ORDER SPECTRUM
Measures by Mr. Van Maanen

LAT.	Δ		PLATE NO.	LAT.	Δ		PLATE NO.
	λ 5812	λ 5828			λ 5812	λ 5828	
N 60°....	......	+13.2	25	N 6°....	......	+ 3.3	21
60.....	+12.9	+11.4	23	S 2.....	......	− 1.8	21
52.....	......	− 0.8	10	12.....	......	− 8.2	21
50.....	+ 1.7	......	39	20.....	......	− 7.9	21
50.....	+11.2	+11.2	37	27.....	− 4.5	− 8.6	48
45.....	+ 6.4	+ 6.6	24	33.....	−10.2	− 7.1	41
44.....	+10.2	− 2.3	29	35.....	......	− 6.9	21
43.....	+16.0	+ 5.0	23	36.....	− 2.5	− 1.3	48
43.....	......	+10.2	25	40.....	− 8.6	− 1.0	11
42.....	+ 0.3*	+ 1.7*	31	43.....	−11.9	+ 0.7	4
40.....	+ 9.4	+ 2.3	10	43.....	− 4.0	− 7.3	41
40.....	......	+ 3.0	37	46.....	......	− 2.6	27
38.....	+ 4.1	+ 7.6	39	47.....	− 6.6	− 4.6	48
38.....	+ 8.9	+ 7.6	24	47.....	(+11.2)	(+11.6)	26
37.....	+15.2	+ 2.1	30	50.....	− 2.6	− 3.6	4
37.....	+ 3.0	− 1.2	29	52.....	− 8.2	−14.8	11
33.....	......	+ 3.3	25	56.....	......	0.0	27
32.....	0.0*	......	31	57.....	(+ 9.2)	(+ 7.9)	26
30.....	+ 7.9	+ 2.8	30	60.....	......	−11.9	4
29.....	(− 8.2)	+ 6.9	29	S 60.....	− 9.6	− 8.9	48
N 28.....	+ 7.6	+ 4.6	24				

* Half-wave plate −22°.5. Displacements should be zero.

Most of these agree with Miss Lasby's measures in sign, but there appears to be a systematic tendency on her part toward larger values. Several other members of the Observatory staff also measured a number of the plates, but although in many cases the internal agreement of their measures was good, the results of different observers for the same plate frequently differed widely. It appeared that a radically different method of measurement, which would

[1] Adams and Lasby, "An Investigation of the Rotation Period of the Sun," *Publications of the Carnegie Institution of Washington*, No. 138.

TABLE VI

FIRST SERIES—λ 5929.898 IN THIRD-ORDER SPECTRUM
Measures by Miss Lasby and Mr. Van Maanen

Lat.	Δ		Plate No.	Lat.	Δ		Plate No.
	L.	V. M.			L.	V. M.	
N 60°....	....	+ 3.3	23	N 26°....	....	+ 1.8	42
60.....	....	+ 9.2	25	25.....	+ 7	− 0.7	44
58.....	+ 6	+ 4.0	42	25.....	+ 8	+ 7.4	55
58.....	....	+ 4.8	55	22.....	+ 7	− 1.3	46
56.....	+13	......	10	19.....	....	+ 3.1	51
55.....	....	(− 7.9)	40	18.....	....	− 0.7	42
55.....	+12	11.4	44	18.....	+ 7	+ 1.7	49
54.....	+15	(− 4.5)	46	16.....	+ 6	+ 1.0	44
50.....	+ 7	......	36	16.....	+ 9	− 0.2	55
50.....	+ 5	+ 7.9	37	15.....	+ 6	......	46
50.....	+ 7	− 0.3	39	12.....	....	− 0.7	51
45.....	+ 7	+ 4.0	35	10.....	+ 5	+ 2.3	49
45.....	....	+ 4.5	24	8.....	+ 5	− 3.3	44
45.....	+ 7	+ 4.0	40	8.....	+ 6	− 0.2	55
45.....	+10	+ 5.1	42	7.....	+ 3	......	46
45.....	+12	+ 2.0	44	6.....	....	+ 1.6	21
45.....	....	+ 7.6	49	5.....	0	+ 4.6	51
45.....	....	+ 5.4	55	4.....	0	......	54
44.....	....	+ 3.3	29	3.....	+ 3	+ 2.0	49
43.....	....	+10.4	25	N 1.....	− 1	......	55
43.....	....	+ 6.4	23	0.....	....	+ 3.0	15
42.....	+ 9	......	32	0.....	+ 2	− 1.3	44
42.....	+ 3*	+ 4.0*	33	S 2.....	....	− 4.6	21
42.....	+11	+ 4.0	46	2.....	+ 6	......	43
40.....	+ 4	+ 6.3	34	2.....	− 2	+ 4.1	45
40.....	....	+ 2.8	37	4.....	− 2	......	54
40.....	....	− 1.8	17	5.....	+ 3	− 0.7	49
40.....	....	(− 5.6)	10	6.....	− 2	+ 0.3	15
39.....	....	+ 9.9	40	7.....	....	− 4.3	19
38.....	....	+ 3.0	24	7.....	− 3	......	44
38.....	+10	......	25	10.....	− 2	− 0.8	45
38.....	....	+ 3.6	39	10.....	− 2	+ 1.7	50
37.....	....	− 3.6	29	12.....	....	− 1.3	21
37.....	+ 1	+ 1.1	30	12.....	....	− 0.3	15
37.....	+16	+ 5.0	49	12.....	....	− 4.3	19
36.....	+12	......	23	12.....	− 2	......	54
35.....	+14	+ 4.1	42	16.....	− 4	......	47
35.....	+ 8	+ 1.5	44	17.....	− 6	− 0.3	45
35.....	+ 8	+ 4.5	55	17.....	− 3	− 0.2	50
34.....	+10	− 2.0	17	18.....	....	− 8.4	19
33.....	+16	......	24	18.....	− 4	......	43
33.....	....	+ 0.7	25	20.....	....	− 5.6	21
32.....	+10	− 1.0	46	20.....	− 8	......	54
30.....	....	− 0.8	23	24.....	− 8	......	47
30.....	....	0.0	30	26.....	− 9	− 3.3	45
29.....	....	− 0.3	29	26.....	....	− 1.0	50
28.....	....	(− 8.9)	17	28.....	− 3	......	43
28.....	....	+ 7.6	24	33.....	....	− 9.2	41
28.....	....	+ 7.8	51	35.....	....	− 6.6	21
N 27.....	+ 4	+ 1.0	49	S 35.....	−14	− 4.7	45

TABLE VI—*Continued*

Lat.	Δ L.	Δ V. M.	Plate No.	Lat.	Δ L.	Δ V. M.	Plate No.
S 36°....	− 5	− 5.9	43	S 47°....	....	(+ 8.2)	26
36....	− 5	......	47	52....	....	− 6.6	11
36....	....	− 6.6	50	53....	(+ 9)	− 4.1	18
38....	−12	......	41	55....	(+10)	(+ 4.6)	14
40....	....	− 8.4	11	55....	....	− 3.6*	28
43....	....	− 5.0	41	55....	− 8	......	47
44....	− 6	......	47	56....	(+ 1)	+ 2.5	27
45....	....	− 2.3	18	57....	(+ 8)	(+ 6.2)	26
45....	− 8	− 4.3	43	60....	− 6	− 5.0	43
45....	−13	......	45	63....	....	− 3.5	18
45....	....	− 4.6	50	65....	....	−10.2	14
46....	−16	......	11	70....	−14	......	43
46....	....	− 1.0	14	74....	....	(+ 5.3)	26
46....	....	+ 7.9*	28	S 74....	−10	......	47
S 46....	....	− 2.1	27				

* Half-wave plate at −22°5. Displacements should be zero.

tend to eliminate or at least to modify possible systematic errors, would be of great service as a check on the results.

This was provided in the form of a parallel plate micrometer, the use of which was suggested by Mr. Pease. A plate of plane, parallel glass 12 mm long, 2 mm wide, and 1.14 mm thick, mounted so as to rotate about an axis lying centrally in the plane of the plate, at right angles to its longest dimension, is supported just above the negative to be measured. Any given strip of the spectrum, corresponding to a section of the quarter-wave plate, can be brought under the parallel plate, which exactly equals it in width. The spectrum is observed through an achromatic doublet, magnifying about three diameters. By inclining the parallel plate, the line seen through it is displaced until it comes into coincidence with the line of an adjoining strip. The angle through which the plate is turned is given by an index moving over a divided arc.[1]

The coincidence reading having been obtained, an adjacent spectrum strip is brought underneath the micrometer plate by

[1] In a perfected form of this micrometer, the parallel plate is mounted in the focal plane of the positive eyepiece of a compound microscope. To preserve the optical symmetry of the system, plates of plane parallel glass are fixed on either side of the movable plate, with their surfaces parallel to the plane of the negative. For use with low powers, however, the simple instrument described above is very satisfactory.

shifting the negative. The difference between the coincidence reading for this position and that first obtained gives the angular rotation of the plate corresponding to twice the relative displacement of the spectrum lines. Since the rotation is always small, the multiplication of the difference by a constant gives the value of the displacement expressed in thousandths of a millimeter. Three coincidence readings are made for each spectrum strip and usually six successive strips, involving four settings of the plate, are measured in both directions, the results being combined to a mean value corresponding to the mean latitude of the strips.

Immediately after the construction of the parallel plate micrometer, extended sets of measures of the plates of the first series were undertaken by two members of the Computing Division. Here, again, successive settings upon the same line usually showed a high degree of accordance, but when the displacements for different latitudes were compared, there was no definite agreement or progression in the values when arranged according to latitude. The same was true of a preliminary set of measures made by Mr. Van Maanen with the same instrument. The systematic errors for a latitude (accidental for the series) were so large as completely to mask the displacements revealed by the later measures. None of the three observers had had previous experience with a micrometer of this form, and the result is not surprising when the character of the lines is considered. A continuation of the measures by Mr. Van Maanen led to different results, however. A remeasurement of the plates of the first series showed a decrease in the accidental errors, and brought to light a variation of the displacement with the latitude similar to that shown by the measures of Miss Lasby. It should be repeated that, throughout all the measures, the greatest care was taken to avoid the unconscious effect produced by a knowledge of the conditions under which the photographs were made. As already stated, the measurer knew neither the hemisphere, the latitude, nor the progression of latitudes on any plate; for, after the latitudes of the regions to be measured had been determined, the plate was cut into strips to which arbitrary letters or figures were assigned, by an individual other than the one who made the measures. For the later series

there was a further uncertainty on the part of the measurer, owing to the fact that the quarter-wave plate was used in both the normal and inverted positions (+ and −). The two sections of a photograph were marked *a* and *b* by the observer, usually Mr. Ellerman or Mr. Kohlschütter, with a corresponding entry in the record book for subsequent identification. Sometimes *a* referred to the + position and sometimes to the −; and not infrequently both the *a* and *b* sections were made with the quarter-wave plate in the same position. The matter is explained in detail, because this method of procedure, together with the general consistency of the results included in the discussion, is the basis of the rejection of all of the measures of the first series except those by Miss Lasby and the later set by Mr. Van Maanen. His results are given in Tables V and VI and are shown graphically in Fig. 2, *b*, *c*, and *e*. Mr. Van Maanen's measures agree, on the average, in showing positive displacements in the northern hemisphere and negative ones in the southern, with values decreasing toward a minimum near the equator, but the average displacement is much smaller than that found by Miss Lasby. The systematic differences between the two observers may be due to the very different methods of measurement employed.

SECOND SERIES

As already explained, the observations of this series were made in the second-order spectrum with the 75-foot spectrograph. The difficulties experienced in the measurement of the broad and diffuse lines of the third-order plates of the first series suggested the possibility that the increased contrast and sharpness of the second order might more than offset the disadvantage of the smaller scale, which with the grating employed is 1 Ångström = 2.95 mm at λ 5900. As the scale for the third order is 1 Ångström = 4.90 mm, the dispersion is 1.66 times that of the second order. The measures of the second-order plates were all made by Mr. Van Maanen with the parallel plate micrometer. The results, reduced to the scale of the third order, are collected in Table VII, and are illustrated in Fig. 3. The regular use of the quarter-wave plate in both the normal and the inverted positions began with this series. The

TABLE VII

Second Series—λλ 5812.139, 5828.097, and 5929.898 in Second-Order Spectrum. Displacements Reduced to Scale of Third Order

Measures by Mr. Van Maanen

Lat.	Δ λ 5812 +	Δ λ 5812 −	Δ λ 5828 +	Δ λ 5828 −	Δ λ 5930 +	Δ λ 5930 −	Plate No.
N 63°...	.....	.....	.....	.....	−3.3	+2.8	143
62....	+1.1	−1.1	−2.8	−0.6	0.0	−1.6	137
60....	.....	.....	.....	.....	+3.3	−1.9	125
60....	.....	.....	.....	.....	−2.8	−0.6	126
60....	+6.3	+1.1	+6.0	−1.6	−6.9	−1.6	154
58....	.....	.....	.....	.....	+0.3	.....	127
58....	.....	.....	.....	.....	+2.2	.....	127
58....	.....	.....	.....	.....	−3.3	+1.1	129
56....	(−9.9)	+3.3	(−10.4)	+3.0	+2.5	+5.5	130
55....	+6.6	−9.4	+3.8	(−15.4)	+2.2	−3.0	131
53....	.....	.....	.....	.....	−1.9	+1.6	149
43....	+7.2	−5.5	+3.3	−7.7	+0.3	+1.9	146
43....	.....	−5.0	.....	−11.0	.....	+5.5	149
42....	+7.7	.....	+0.6	.....	−7.2	.....	149
38....	.....	.....	.....	.....	+3.0	.....	127
38....	.....	.....	.....	.....	−0.6	.....	127
38....	.....	.....	.....	.....	−1.4	+1.1	129
38....	(−7.2)	(+6.9)	+3.8	(+6.6)	−4.1	+1.1	130
38....	.....	.....	.....	.....	−1.9	+1.9	143
37....	.....	.....	.....	.....	−3.0	−1.6	125
37....	.....	.....	.....	.....	−1.1	+2.2	126
36....	+5.0	−1.6	+6.0	−2.2	+1.6	−0.0	137
35....	+5.8	+2.8	+2.8	0.0	−4.4	−3.6	154
34....	0.0	+5.0	+3.3	(+10.4)	+5.0	−2.2	131
11....	+4.1	−2.2	−2.5	−0.6	−3.6	+4.4	155
10....	.....	−3.6	+2.8	−2.2	0.0	0.0	148
10....	+3.8	+4.7	+1.9	−3.3	+1.6	−4.1	153
N 7....	.....	.....	.....	.....	−5.5	−6.0	159
S 2....	−8.2	+2.8	+7.4	+8.2	−6.3	−0.8	145
4....	.....	.....	.....	.....	−6.0	−2.2	159
4....	+3.8	+7.7	−1.1	−0.6	−2.2	+7.7	155
5....	+2.2	−1.1	+0.8	−8.0	−0.8	0.0	148
5....	.....	−2.8	.....	.....	+4.4	−5.0	153
31....	.....	.....	.....	.....	+3.3	−7.2	147
31....	.....	.....	.....	.....	0.0	−2.2	156
32....	−6.0	+8.0	−7.2	+1.1	−8.2	+4.4	135
34....	.....	.....	.....	.....	−1.6	+3.8	133
34....	.....	.....	.....	.....	−1.6	.....	134
34....	.....	.....	.....	.....	0.0	.....	134
35....	−6.0	+1.4	−3.3	+1.6	+6.3	−1.1	142
41....	.....	.....	.....	.....	−6.6	+1.9	144
41....	+0.6	+5.5	−6.3	+3.8	−6.0	+4.4	160
51....	.....	.....	.....	.....	+3.3	−6.0	156
53....	−3.3	+1.1	+1.1	+9.9	−3.8	+5.5	135
53....	.....	.....	.....	.....	+2.8	−5.5	147
55....	.....	.....	.....	.....	−5.5	+7.7	133
55....	.....	.....	.....	.....	+1.6	.....	134
55....	.....	.....	.....	.....	+0.3	.....	134
60....	.....	.....	.....	.....	−2.2	+0.8	144
S 62....	0.0	+10.4	−3.3	+7.7	+3.8	+1.1	142

results are given separately and are distinguished by the signs + (normal) and − (inverted) in the table heading. The preponderance of the number of cases of opposite sign in the + and − columns is at once evident. As was anticipated, the measurement of the plates was less fatiguing than in the case of the third order, but

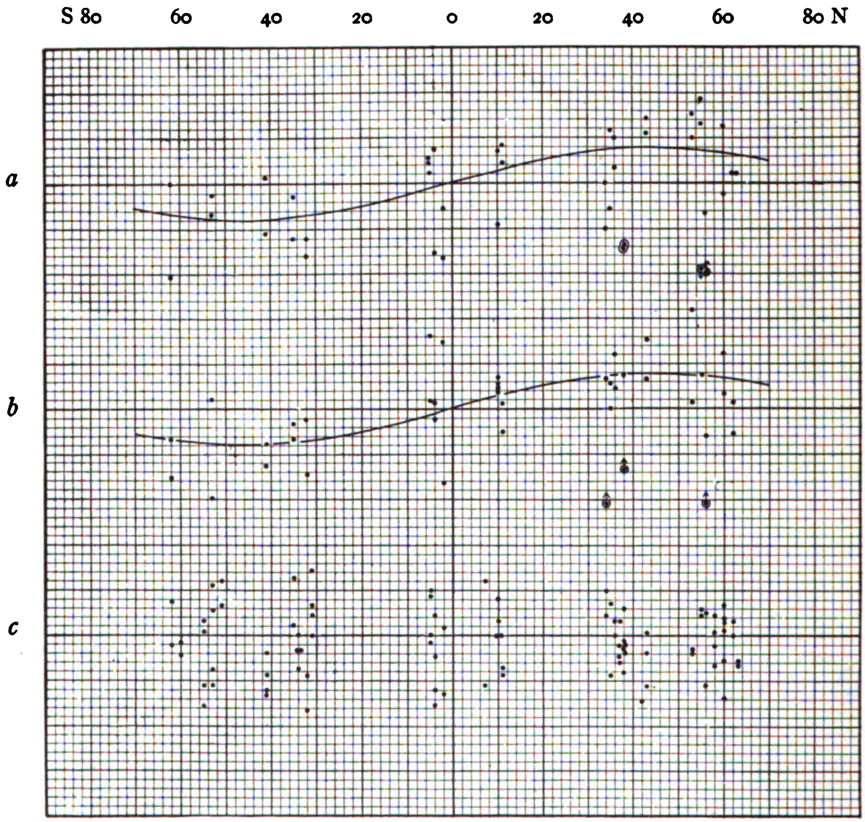


FIG. 3.—Displacements for the second series, measured by Mr. Van Maanen *a*, λ 5812; *b*, λ 5828; *c*, λ 5930. Vertical scale: 1 division = 0.001 mm.

the results did not confirm those of the first series. They raise, however, a question of considerable interest which is discussed below (p. 74).

As stated on p. 42, a number of second-order plates were also made with the small solar image formed by the 30-foot (9.1 m)

objective. None of the measures on these plates is included in the discussion. They give negative results which are not printed in detail, as the difficulty experienced with the second-order plates is sufficiently indicated by the measures on λ 5930 in the second series.

THIRD AND FOURTH SERIES

The negative character of the results from the observations in the second-order spectrum led to a return to the third order for the third and fourth series. The observing arrangements were the same for these two series, and the distinction between them is only that of the lines observed and the dates covered by the observations. It will be noted, however, that the fourth series includes mainly the higher latitudes, both N. and S.

The results of Mr. Van Maanen's measures with the parallel plate micrometer for these two series are given in Tables VIII and IX, the unit, as before, being 0.001 mm. An examination of the tables, or a glance at Figs. 4–6, shows at once a variation of the displacement with the latitude similar to that revealed by the first series. The detailed discussion of all of the results is given below (p. 73).

SOURCES OF ERROR

The systematic difference between the measures made by Miss Lasby with the Toepfer comparator and those by Mr. Van Maanen with the parallel plate micrometer, referred to in connection with the first series, made it desirable to provide a method of determining the nature and magnitude of systematic errors incident to the measurement of any type of spectral line. An instrument for this purpose would be of great service in giving the personal equation of each observer taking part in an investigation. Apparently the best means of accomplishing this is by the measurement of a known displacement of the line in question. Such a displacement is easily produced by means of a plane parallel glass plate, mounted before the negative, and inclined at a known angle. The calculated displacement can be checked, if desired, by the measurement under a high-power microscope of a fine line engraved on the film of the negative parallel to the lines of the spectrum.

TABLE VIII

THIRD SERIES—λ 5929.898 IN THIRD-ORDER SPECTRUM
Measures by Mr. Van Maanen

Lat.	Δ		Plate No.	Lat.	Δ		Plate No.
	+	−			+	−	
N 66°....	+ 1.6	− 5.8	230	N 35.....	+ 6.4	......	200
62.....	+ 6.8	......	181	35.....	+ 3.6	......	233
60.....	+ 5.3	......	193	32.....	......	− 1.3	200
60.....	+ 9.9	− 3.0	184	11.....	− 7.9	− 3.0	203
59.....	− 3.3	......	212	7.....	+ 6.3	− 4.4	203
59.....	......	+ 4.0	200	N 2.....	− 5.0	+ 0.7	203
59.....	+ 7.6	......	223	S 2.....	− 0.1	− 1.6	203
59.....	+ 3.3	− 4.3	230	6.....	− 0.3	+ 1.3	203
58.....	+ 2.8	......	200	33.....	......	+ 8.9	187
56.....	+ 9.2	......	233	33.....	+ 5.0	+10.9	220
54.....	− 0.7	......	212	33.....	+ 4.6	......	212
54.....	+ 7.1	......	223	33.....	......	− 5.0	211
54.....	+ 5.6	......	223	33.....	− 8.6	+ 4.3	196
53.....	+ 5.1	......	200	34.....	− 9.7	(+19.5)	185
53.....	+ 1.6	− 4.8	230	36.....	− 9.9	......	194
53.....	+11.9	− 7.8	184	37.....	+ 4.8	......	233
53.....	+ 6.9	......	181	37.....	− 2.6	+ 5.6	232
52.....	......	− 1.2	200	37.....	(+ 5.6)	......	212
52.....	+ 6.9	......	233	37.....	......	(−5.9)	211
51.....	+ 4.6	− 1.6	217	38.....	− 5.3	+14.7	185
49.....	+ 4.0	− 5.9	230	38.....	− 6.6	+ 6.9	226
48.....	0.0	......	200	38.....	......	+ 9.2	220
47.....	+ 6.3	− 5.4	217	38.....	− 0.7	......	196
46.....	− 4.1	......	212	39.....	− 5.6	......	233
46.....	+ 6.6	− 2.5	181	39.....	− 7.6	+ 4.3	232
45.....	+ 9.2	......	223	42.....	− 3.1	......	194
45.....	+ 5.0	......	223	43.....	(+ 8.6)	......	212
45.....	− 2.0	− 1.2	230	43.....	......	− 2.0	211
45.....	+ 6.3	−11.6	184	45.....	− 9.9	+ 2.0	226
43.....	+ 6.3	−11.4	193	45.....	(+ 7.4)	+ 8.1	220
43.....	+ 4.1	(+ 8.6)	200	47.....	−15.5	+14.4	185
43.....	+ 6.9	......	233	47.....	− 2.6	......	233
43.....	......	− 6.9	192	47.....	− 5.3	+ 7.6	232
42.....	(− 6.3)	......	212	47.....	+ 5.0	......	212
42.....	+ 5.3	− 9.6	181	47.....	− 8.6	+12.5	196
41.....	......	+ 3.5	200	48.....	......	+ 1.3	211
41.....	+ 6.9	......	223	49.....	− 7.3	+ 5.8	226
41.....	+ 3.3	......	223	50.....	+ 5.0	+11.6	220
41.....	......	− 4.3	230	52.....	−10.6	+12.2	185
39.....	+ 6.3	−11.4	193	52.....	− 3.5	......	233
39.....	+ 2.3	......	230	52.....	− 6.9	+ 5.0	232
39.....	+ 6.6	......	233	52.....	− 6.3	+ 9.6	196
39.....	......	− 4.6	192	53.....	+ 3.3	+ 4.3	220
37.....	(− 8.9)	......	212	53.....	(+ 6.9)	......	212
37.....	......	− 4.4	181	55.....	− 4.4	+ 1.0	226
36.....	......	+ 2.6	200	57.....	− 5.6	......	233
36.....	+ 3.1	......	223	S 57.....	− 5.0	+ 6.4	232
N 36.....	+ 5.8	......	223				

TABLE IX

FOURTH SERIES—λλ 5812.139 AND 5828.097 IN THIRD-ORDER SPECTRUM
Measures by Mr. Van Maanen

LAT.	Δ λ 5812 +	Δ λ 5812 −	Δ λ 5828 +	Δ λ 5828 −	PLATE NO.
N 71°.......	−2.6	.....	+2.6	.....	276
70........	+0.3	.....	+0.7	.....	274
68........	+0.7	.....	+1.6	.....	272
68........	+4.4	.....	+2.0	.....	273
64.......	+1.3	.....	+1.8	.....	271
63........	+4.0	.....	+1.8	.....	274
60........	+4.8	.....	+3.0	.....	273
59........	+1.8	.....	+2.3	.....	276
58........	+3.6	.....	+0.8	.....	272
58........	+2.6	.....	+3.3	.....	271
50........	+4.1	.....	+3.6	.....	273
50........	+5.0	.....	+3.0	.....	274
49........	+4.3	.....	+6.9	.....	276
47........	+8.2	.....	+5.3	.....	272
47........	(−1.6)	.....	+6.3	.....	271
45........	+4.6	.....	+7.4	.....	274
44........	+6.9	.....	(+9.6)	.....	276
44........	+5.9	.....	+5.0	.....	273
42........	+6.9	.....	+6.9	.....	271
41........	+5.3	.....	+5.3	.....	272
40........	+4.6	.....	+5.0	.....	273
40........	+8.2	.....	+2.6	.....	274
38........	+4.0	.....	+5.0	.....	276
37........	+5.3	.....	+2.8	.....	271
36........	+2.3	.....	+1.0	.....	272
36........	+5.0	.....	+5.6	.....	273
36........	+5.0	.....	+7.3	.....	274
35........	+3.0	.....	+4.3	.....	271
30........	+5.3	.....	+3.3	.....	275
27........	.....	(+5.9)	.....	(+4.0)	275
26........	+2.6	.....	+3.3	.....	275
21........	+3.0	.....	+3.0	.....	288
21........	+6.0	.....	+4.4	.....	288
20........	+3.5	−3.0	+5.3	−3.0	275
17........	+5.3	.....	+4.6	.....	288
17........	+2.5	.....	+3.5	.....	288
16........	+2.5	−2.5	+2.3	−3.6	275
14........	+3.3	.....	−0.5	.....	288
14........	−0.3	.....	+0.3	.....	288
12........	+4.4	−2.0	+2.0	−1.8	275
10........	+1.5	.....	+0.8	.....	288
10........	+2.5	.....	+0.5	.....	288
9........	+2.6	.....	0.0	.....	275
5........	+0.3	.....	+1.2	.....	288
5........	+2.0	.....	+0.8	.....	288
1........	+2.0	.....	−0.3	.....	288

TABLE IX—*Continued*

Lat.	Δ λ 5812 +	Δ λ 5812 −	Δ λ 5828 +	Δ λ 5828 −	Plate No.
N 1°	−2.6	.....	−1.5	.....	288
0	.....	−1.3	.....	−0.7	290
0	.....	−1.3	.....	+0.7	290
S 3	.....	+1.6	.....	0.0	290
3	.....	+1.5	.....	+0.3	290
7	.....	+2.0	.....	+1.0	290
7	.....	−1.3	.....	.....	290
12	.....	+3.6	.....	+4.0	290
12	.....	−0.5	.....	+1.8	290
17	.....	+4.6	.....	+2.6	290
17	.....	+4.1	.....	+2.8	290
19	−1.6	.....	−2.6	.....	283
21	.....	+5.6	.....	+2.3	290
21	.....	+2.3	.....	+3.0	290
22	−2.6	.....	−2.0	.....	283
24	(+7.9)	.....	(+7.4)	.....	280
28	−2.6	.....	−4.0	.....	283
28	(+4.8)	.....	(+5.9)	.....	280
31	−2.6	.....	−5.3	.....	283
34	+1.0	.....	(+3.3)	.....	280
35	−4.3	.....	−5.9	.....	283
37	−5.6	.....	−2.6	.....	283
37	.....	.....	(+4.6)	.....	280
39	−4.6	.....	−1.3	.....	261
39	−1.3	.....	−5.3	.....	283
41	−4.6	.....	−3.6	.....	283
42	.....	+7.9	.....	+5.1	261
42	−3.0	+4.4	−4.3	+4.6	258
44	−8.2	+4.3	−4.0	+3.5	261
46	(+3.0)	+5.3	(+5.6)	+3.6	258
47	(+8.2)	.....	(+5.6)	.....	279
47	(+1.6)	.....	−3.0	.....	265
47	−3.0	+6.9	−4.3	+2.6	264
47	−4.6	.....	−3.0	.....	255
48	.....	(−4.0)	.....	+6.6	265
48	−4.6	.....	−2.6	.....	283
49	.....	+3.6	.....	+4.3	255
51	(+4.3)	.....	(+2.0)	.....	279
51	−1.6	.....	−2.0	.....	283
51	−9.6	+8.7	−5.9	+4.3	265
51	−2.3	+4.6	−2.6	+5.0	264
52	−4.0	+5.0	−2.0	+6.4	255
52	−7.6	+4.3	−0.8	+3.3	261
52	−2.6	+5.3	−5.9	+4.1	258
56	−5.0	+3.0	.....	+2.6	258
57	−5.0	+7.4	−5.0	+4.0	261
59	−4.6	+5.9	−1.3	+2.6	265
59	(+4.6)	.....	(+2.8)	.....	279
60	−2.0	.....	−2.3	.....	283
60	+0.3	+1.8	−4.1	+4.0	264

TABLE IX—*Continued*

LAT.	Δ				PLATE NO.
	λ 5812		λ 5828		
	+	−	+	−	
S 60°.......	−4.0	+4.3	−3.0	+3.6	255
62........	−3.0	+0.8	−7.4	+8.1	261
63........	−4.6	+4.3	−2.0	−0.5	258
64........	−1.3	.....	−0.5	.....	283
65........	0.0	.....	−1.6	+1.6	265
65........	.....	.....	(+3.6)	.....	279
66........	−1.5	+0.3	−3.0	+4.3	255
66........	−0.7	+0.3	−0.3	+2.0	264
68........	−2.6	.....	−1.3	.....	261
72........	(+2.0)	.....	+1.3	.....	279
72........	−0.7	+4.6	−0.8	+0.7	265
72........	−1.0	.....	−1.3	.....	255
73........	.....	+0.3	.....	+0.8	255
73........	+0.2	+1.3	−1.6	+0.8	264
78........	+2.3	.....	+2.1	.....	279
79........	+1.0	.....	−0.3	.....	255
79........	(+3.0)	−0.2	−0.3	+0.3	264
S 82........	+3.3	+1.3	−0.8	+1.0	265

A preliminary test of this method had indicated that under certain conditions, which probably depend upon the granular structure of the plate,[1] a line actually displaced toward the red may appear to be displaced toward the violet. Mr. Babcock, to whom I am indebted for much assistance in connection with the present work, selected a third-order photograph at λ 5930, taken at the sun's equator, and showing no relative displacement of the line in successive strips. A plane parallel glass plate, equal in width to one of the strips, was mounted above it at a small angle, sufficient to displace a line seen through it by +0.004 mm. Two photographs were taken of the spectrum, showing the displaced line and two adjoining strips, which were covered with plates of plane parallel glass, with their faces parallel to the film, to compensate for focus. These photographs, which were exactly alike in all known respects, may be called A and A′. Another photograph (B), show-

[1] Perrine, "Some Results of a Study of the Grain and Structure of Photographic Films," *Lick Observatory Bulletin*, No. 143; "Results of Some Further Studies of the Structure of Photographic Films and the Effect on Measures of Star Images," *ibid.*, No. 148.

ing a displacement of −0.025 mm, was also taken. The line λ 5930 was then measured on the three photographs by Mr. Adams and Mr. Van Maanen, after Mr. Babcock had determined the actual displacements by measuring with a high power several sharp artificial lines on both sides of λ 5930. The results of the measures of λ 5930 made by Mr. Adams with a measuring machine of the ordinary kind (micrometer screw and cross-wire), and by Mr. Van Maanen with the parallel plate micrometer previously described, are given below.

Plate	Actual Displacement	Measured Displacement	
		Adams	Van Maanen
A	+0.004 mm	+0.002 mm	+0.0036 mm
A′	+0.004	−0.001	−0.004
B	−0.025	−0.026	−0.014

It thus appears that two apparently identical copies of the same photograph may differ in such a way as to transform an actual positive displacement into an apparent negative one.

The method appears so promising that a special instrument is being constructed for the further study of personal equation and systematic errors. In this instrument a strip of plane parallel glass, mounted between two fixed strips of equal width (2 mm) can be set at any desired angle with the plane of the negative. The resulting displacement of the solar line is then measured with an ordinary eyepiece micrometer or with a parallel plate micrometer easily substituted for it.

So much for systematic errors, the further discussion of which must await the completion of this instrument. As for errors due to other causes, we have already seen, in the case of the iodine absorption spectrum, the absence of such disturbing effects as might enter from lack of stability, changes of temperature, imperfect resolution, or small linear dispersion in the spectrograph. Unfortunately the solar lines are much less sharp than those of iodine, and the difficulties of measurement are far greater. This sets a limit to the accuracy attainable, but the errors arising from this source are of an accidental nature, and certainly could not be

conceived to account for the observed relationship between latitude and displacement, or the reversal of sign in the two hemispheres. Other possible sources of error are: (1) unequal illumination of the grating; (2) heating of the slit jaws; (3) imperfect orientation, centering, and guiding, and poor definition or distortion of the solar image; (4) elliptical polarization by the silvered coelostat mirrors; (5) polarization in the spectrograph; (6) imperfect correction of the quarter-wave plate.

These may be discussed in turn:

1. As a complete set of measures involves the use of four quarter-wave strips, covering 8 mm of the slit, and as the light from each part of the slit falls upon the grating in a slightly different way, very small differential displacements might conceivably be produced. It has been shown above, however, that the ruled surface in the first series of observations was much more than covered by the beam from the objective (ratio of aperture to focal length = 1/60, while the corresponding ratio for the spectrograph = 1/181), and in the later work with the objective of 150 feet (45.7 m) focal length there was still a safe margin. A decisive test for such displacements is afforded by the atmospheric lines, one of which falls very near λ 5930. This was measured by Miss Lasby on a large number of plates, but never showed a displacement exceeding 0.002 mm, which is well within the errors of measurement.

2. With a ratio of aperture to focal length of 1/60 in the telescope, the heating of the slit jaws is very slight, especially after the introduction of the quarter-wave plate and Nicol. In any event, this would produce merely a slight widening of the slit, without effect in purely differential measures. A sufficient check is again afforded by the atmospheric lines.

3. On account of the solar rotation, displacements of a solar line may result from errors in the orientation or centering of the solar image, or from imperfect guiding during the exposure. Poor definition of the image, due to atmospheric disturbance, change of focus or astigmatism of the mirrors, may introduce a small effect of the same kind. For the 17-cm solar image, a departure of the slit from the central meridian of the sun amounting to 1.5 mm may be regarded as a maximum effect of such causes. This would

correspond at the equator to a displacement of about 0.001 Ångström, decreasing to about two-thirds of this amount at the limb. A combination of the above error in centering with an error (very extreme) of 1° in orientation, would involve a displacement of about 0.0013 Ångström at the limb. In either case, it is evident that the differential measures of the present investigation would not be appreciably affected by this cause.

4. Circularly polarized light, falling on the silvered surfaces of the two coelostat mirrors, becomes elliptically polarized, and incident light elliptically polarized has its ellipticity modified. While it can be shown that the polarization produced in unpolarized incident light by metallic reflection cannot cause displacements of the kind observed, it is quite possible that the change in the ellipticity of polarized light might be great enough to affect the displacements. For the rapid and convenient study of the change in ellipticity corresponding to any given declination and hour angle of the sun, a special polarimeter has been constructed in the Observatory instrument shop. This is essentially a small model of the tower telescope, provided with polarizing and analyzing attachments (Plate IV, *b*). At the upper end of the polar axis of the model coelostat an adjustable bronze arc, carrying a small incandescent lamp, is attached. By varying the length of the arc the incandescent lamp can be made to coincide in direction with the sun at any declination. Thus rotation of the polar axis will cause the incandescent lamp to move through a path corresponding to the path of the sun in the heavens, for the date in question. The light of the incandescent lamp, rendered parallel by a collimating lens, falls upon a Nicol prism and subsequently upon a quarter-wave plate, set so that its principle section makes an angle of 45° with the short axis of the Nicol. By setting the principal section to the left or right, right-handed or left-handed circularly polarized light can be produced at will. After falling upon the coelostat mirror the light is reflected to the second mirror and then to a small telescope, over the object-glass of which is mounted a quarter-wave plate and a Nicol prism. After the instrument has been set for the proper declination and hour angle, it is then only necessary to turn the quarter-wave plate and the Nicol prism on the observ-

ing telescope until the light of the incandescent lamp is completely extinguished. The position of the principal section of the quarter-wave plate and the major axis of the ellipse, as given by a divided circle, furnish the data required. It should be added that since the quarter-wave plate is corrected for a particular wave-length, it is necessary to place a piece of colored glass over the incandescent lamp in order to secure nearly complete extinction.

It is evident that the displacements of the polarized components of a solar line will not be affected unless the ellipticity of the light is altered sufficiently to affect the degree of its extinction, and consequently the center of gravity of the resultant line. As a convenient check on the performance of the compound quarter-wave plate and Nicol under the exact conditions of observation, the polarimeter is so constructed that these can be mounted for use with it (see Plate IV, *b*). In case the extinction is incomplete, a half-wave plate, inserted between the compound quarter-wave plate and Nicol, is rotated until the intensity of the light transmitted by alternate strips of the quarter-wave plate is reduced to a minimum.

For the preliminary investigation of the sun's magnetic field described in this paper, the compound quarter-wave plate and Nicol, used without an intervening half-wave plate, have been found to give sufficiently complete extinction for all declinations of the sun, provided the hour angle is not too great. In the definitive investigation soon to be undertaken, small corrections to the observed displacements may become necessary, but these will not affect the general conclusions.

An examination of the matter from a theoretical standpoint leads to a similar conclusion. The expression for the resultant displacement, including the effect of the change in ellipticity, indicates that the mirror polarization is such as to make the observed displacements slightly smaller than they would otherwise have been. For any given conditions of incidence, the change in ellipticity flattens but does not modify the general character of the curve or shift the maximum and minimum in latitude.[1]

5. Under certain conditions, the polarization produced by the slit and grating of a spectrograph may profoundly influence the

[1] Seares, *Contributions from the Mount Wilson Solar Observatory*, No. 72; *Astrophysical Journal*, 38, 99, 1913.

relative intensities of spectrum lines due to light initially polarized.[1] The spectrograph polarization was examined by Mr. Ellerman by photographing the solar spectrum successively upon the same plate with a constant exposure, a Nicol in front of the slit being rotated 22°.5 between the successive exposures. The λ 5930 region of the third order shows no appreciable variation of intensity with the rotation of the Nicol, from which it appears that for this order and region the polarization must be very small. The corresponding region for the second order shows, however, a strong effect, the relative reduction in intensity for two positions of the Nicol differing by 90° amounting apparently to about 40 per cent. It happens, however, that the position of the Nicol for the most favorable transmission corresponds approximately to that of the long Nicol used in the observations for the general field, so that even here there can scarcely have been any changes in intensity. But admitting even the presence of such a change, it is difficult to see how the relative displacements could have been seriously modified. For under the conditions of observation, the light entering the slit from all the components of the solar line is plane-polarized in the same plane, owing to the presence of the Nicol in front of the slit which transmits only those vibrations parallel to the slit. The spectrograph polarization cannot, therefore, change the relative intensities of the components in any spectrum strip, and, hence, apparently cannot displace the maximum of the resultant line. In the case of a very unsymmetrical resultant line, however, which does not occur with a normal triplet for Zeeman separations of the magnitude of those observed, it is conceivable that a small apparent relative shift in two adjacent spectrum strips might be introduced. But the displacements of such a line would also be affected by the conditions of exposure and development, and would be likely to present anomalies revealing its presence.

6. Two compound quarter-wave plates have been used for the work on the lines λ 5812, λ 5828, and λ 5930: one by Werlein, corrected for λ 6300, and one made in our laboratory by Mr. Babcock, corrected for λ 5650. For the latter, as tested by Mr. Babcock,

[1] Zeeman, *Proceedings of the Royal Acad. of Sciences of Amsterdam*, November 28, 1907; November 8, 1912.

the intensity of the component totally quenched at λ 5650 is 1.6 per cent at λ 6500, 0.6 per cent at λ 5930, and 2.3 per cent at λ 5100. For the Werlein plate, assuming the same rate of divergence, the intensity of the weak component at λ 5930 would be 0.8 per cent of the intensity of the strong component.

DISCUSSION OF THE OBSERVATIONS

An examination of the tables and curves representing the first, third, and fourth series of observations, all of which were made in the third-order spectrum, shows at once a marked grouping of positive displacements in the northern and of negative displacements in the southern hemisphere (quarter-wave plate in the normal or + position), with values decreasing, on the average, from middle latitudes toward the equator. The fourth series, which includes the higher latitudes, also shows a decrease toward the poles. There are various discrepancies of sign, some of which may represent mistakes of record. For example, Plates 26 and 27 may have been made in the northern hemisphere, though recorded as in the southern, since both Miss Lasby and Mr. Van Maanen obtain values which give positive mean displacements (see Tables IV, V, and VI).

As a further illustration of possible mistakes in record, Plates 279*b* and 280*a*, both made in the southern hemisphere with the quarter-wave plate in the + position, show positive values of the displacement for both lines at all of the latitudes measured (see Table IX, latitudes S. 24, 28, 34, 37, 47, 51, 59, 65, 72, 78).

But quite irrespective of these discordances, and notwithstanding the fact that there are systematic differences in the results for different lines and series, a variation of the displacement with the latitude is clearly shown in all cases excepting for λ 5930 in the second series. If in Miss Lasby's measures for the first series, including 103 values, we disregard the 10 discordant displacements in parentheses in Tables IV and VI, the results are remarkably consistent. Of the 10 discordant values, 6 are from the two plates, Nos. 26 and 27, referred to above. The remaining 4 are from Plates 14 and 18. It may be noted that Mr. Van Maanen's measures of the same region on Plate 14 are also positive, though

for latitudes S. 46° and S. 65° on the same plate he obtains the negative sign (Table VI).

We have already considered briefly the question of systematic errors (p. 63), which may depend upon both personal equation and on the very different types of measuring machines employed by the two observers. As soon as the machine for the study of systematic errors is completed, this point will be fully investigated. The present problem is to detect the sun's magnetic field and determine its polarity; the measurement of its intensity over a wide range of level and the accurate location of the poles may follow.

We have still to consider, however, the difference between the results of the second and third orders, and the peculiar behavior of λ 5930, which shows little, if any, change of displacement with latitude on the second-order plates. The first question that presents itself is whether any fundamental distinction exists between the spectra of the second and third orders, which might account for the observed effects. The influence of polarization in the spectrograph, which usually varies from one order to another, has already been discussed (p. 72), and it seems unlikely that this can have played any part. Differences in contrast and photographic structure of the lines may afford a possible explanation. I accordingly asked Dr. Anderson to make a microscopic examination of the three lines in question on plates of the second and third orders. It is a well-known fact that in a region where the density of the images changes rapidly, the silver grains are not uniformly distributed. They tend to group themselves in irregular lines or patches with lanes between them in which few, if any, dark silver grains are present. This phenomenon was investigated by Perrine in the case of star images and reproductions of enlarged photographs accompany his papers.[1] The width of the region of irregular distribution for λ 5930 was found to vary between 0.06 mm and 0.09 mm on second-order plates, while on third-order plates its width is from 0.08 mm to 0.012 mm. One striking difference, however, was noted, which may perhaps be due to the smaller contrast of the third-order plates: the distribution of the silver grains over the edges of the line is very much more uniform in the

[1] *Loc. cit*

third than in the second-order plates. In fact, on some of the plates the distribution is so nearly uniform that there was some difficulty in locating "the region of irregular distribution." From Perrine's results it would appear that such a difference would have a very important effect upon the measures, and might possibly account for the difference found between the two orders. To test this point, plates with less contrast will be made in the second order.

The differences between λ 5930 and $\lambda\lambda$ 5812 and 5828 indicated by the first and second series is perhaps rendered questionable by the fact that Mr. Van Maanen's numerous measures on $\lambda\lambda$ 5812 and 5828 in the fourth series give a curve whose maximum is practically identical with that for λ 5930 in both the first and third series. But, a real difference in displacement would in nowise be surprising, for the lines are of different intensities ($\lambda\lambda$ 5812 and 5828, intensity 0; λ 5930, intensity 2) and may represent different solar levels. It is also quite possible that their Zeeman separations for the same field strength are different.

In the early part of this investigation, when there was difficulty on the part of some observers in checking Miss Lasby's results, it occurred to me that a simple means might be employed to determine the nature of the displacements. If they are really magnetic, rotation of the Nicol prism through an angle of 90° should change a positive displacement into a negative one. As already remarked, the effect of turning the Nicol is accomplished in the present apparatus by rotating a half-wave plate, mounted between the Nicol and the compound quarter-wave plate. When the principal section of the half-wave plate is set so as to coincide with the long axis of the Nicol, the displacements of the solar lines should be the same as when no half-wave plate is used. Rotation of the half-wave plate through an angle of 22°.5 should annul the displacements and cause the sections of the solar lines, in all of the successive strips, to lie in their normal position. Further rotation of the half-wave plate to a point where its principal section makes an angle of 45° with the axis of the Nicol, should restore the displacements, but their signs should be opposite to those observed when the half-wave plate stood at 0°. The atmospheric lines should not be affected, as they are not produced in a magnetic field.

The photographs with which the half-wave plate was used are indicated in the last column of Table III. When necessary, the signs of the corresponding displacements have been reversed to reduce them to the normal or zero position before inserting them in the tables containing the detailed results. Those corresponding to the 22°5 position were entered without change, and attention called to the fact that they should be zero (see footnotes, Tables V and VI).

The values of the displacements found by Miss Lasby, with their original signs, are collected in Table X, the unit, as usual, being 0.001 mm. The latitudes for the plates compared are the same. As a check upon any abnormality in the half-wave plate, a different part of the plate was used for Plates 35–39.

TABLE X

REVERSAL OF SIGN WITH ROTATION OF HALF-WAVE PLATE

Plate Nos.	26, 27		29, 30		32, 33, 34			35, 36		37, 38, 39		
λ/2 Plate	0°	−45°	0°	−45°	0°	−22°5	−45°	±180°	−135°	+135°	+157°5	±180°
Atm. line	0	0	...	...	...	0	0	0	0	0	n.m.	0
λ 5812...	+ 8	−4	+8	−6	...	...	...	...	...	...	....	...
λ 5828...	+12	−4	+8	−3	...	...	...	...	...	...	....	...
λ 5930...	+ 8	−1	...	−1	+9	+3	−4	+7	−7	−5	n.m.	+7
Means...	+9	−3	+8	−3	+9	+3	−4	+7	−7	−5	....	+7

These results clearly show that the magnitude of the displacements depends upon the position angle of the half-wave plate, and that their direction can be reversed by turning the plate through an angle of 45°. We may therefore conclude that the light from the red and violet sides of the solar line in question is circularly or elliptically polarized in opposite directions.

Another method of accomplishing the same result is the inversion of the compound quarter-wave plate, now regularly employed in all of our observations. Thus the relative signs of the displacements on the *a* and *b* plates of the second series should afford another check on their magnetic nature.

As previously explained, the columns in Tables VII–IX headed + and − give the observed displacements and the signs obtained

when the quarter-wave plate was in the normal and inverted positions. If the displacements were large, and the source were actually in a magnetic field, the sign of the displacement corresponding to the + and − positions of the quarter-wave plate would always be reversed. In a comparatively weak magnetic field, however, giving very small displacements, the errors of measurement would necessarily tend to mask the effect, and in many cases the expected reversal of sign would not be observed. Table XI indicates the percentage of cases in which a reversal occurs. Those instances in which one of the displacements is zero have been disregarded in calculating the percentages, the number of such cases being indicated in the column headed "Zero Values"; but discordant observations have not been rejected in the comparison.

TABLE XI

REVERSAL OF SIGN WITH INVERSION OF QUARTER-WAVE PLATE

Series	λ	No. Reversed	No. Not Reversed	Rev. + Not Rev.	Zero Values	Percentage Reversed
II..........	5812	13	5	18	2	72
II..........	5828	13	7	20	1	65
II..........	5930	27	9	36	5	75
III.........	5930	32	8	40	0	80
IV.........	5812	21	6	27	0	78
IV.........	5828	24	3	27	0	89
Total...		130	38	168	8	77

From an examination of the table, we find that 130 pairs of plates out of 168, or 77 per cent, show reversal of sign. In view of the relatively large errors of observation, this result strongly supports the hypothesis that the displacements are produced by a magnetic field.

The effect of inverting the quarter-wave plate is graphically shown in Fig. 4, where the measures corresponding to the + and − positions of the plate are plotted separately. Two nearly symmetrical curves result, with opposite slopes, just as theory would indicate in the case of a magnetic field. A similar application of the same method is illustrated by the two curves shown in Fig. 5.

It is important to note that the percentage of reversals for

λ 5930 in the second series is the same as that for $\lambda\lambda$ 5812 and 5828, in spite of the fact that the former line shows, in this series, no

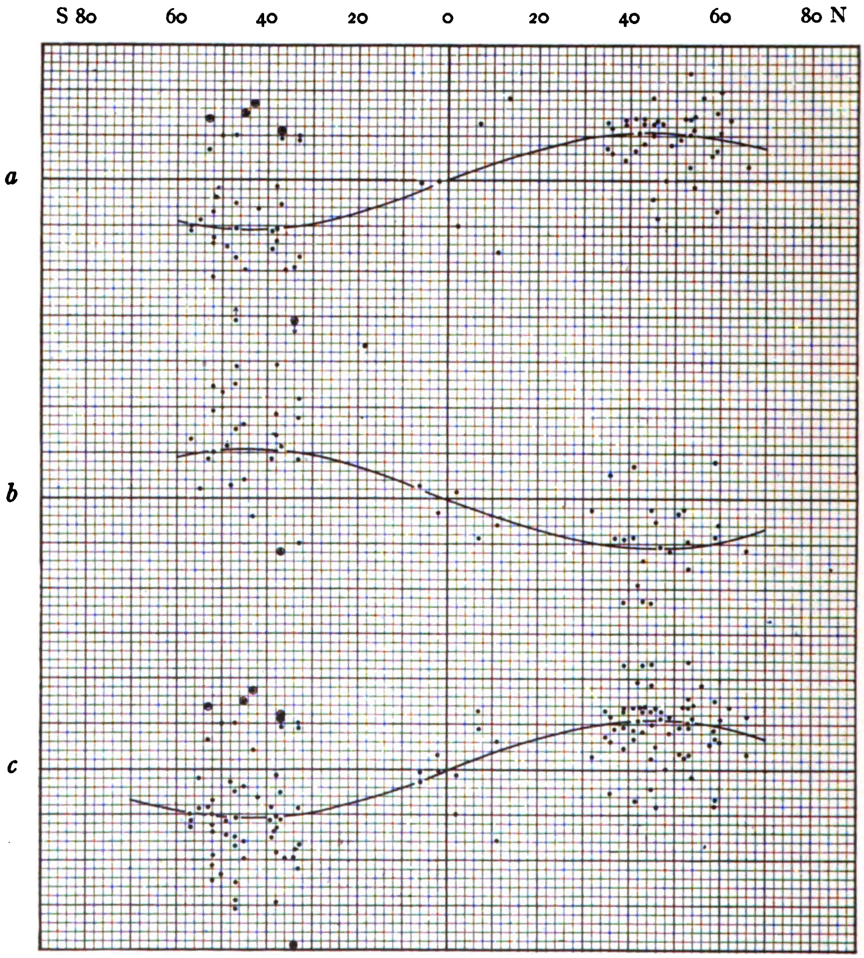


FIG. 4.—Displacements for the third series, λ 5930, measured by Mr. Van Maanen

a, Quarter-wave plate in normal position; *b*, Quarter-wave plate inverted; *c*, Results for *a* and *b* combined, the signs of the displacements for the latter having been changed.

Vertical scale: 1 division = 0.001 mm.

variation of the displacement with the latitude, while for $\lambda\lambda$ 5812 and 5828 it seems clear. This points strongly to the conclusion

that the apparently discordant results for λ 5930 are really magnetic. I am unable to offer any explanation of this anomaly, though attention should be called to the fact that two spots appeared on the sun while the second series was in progress.

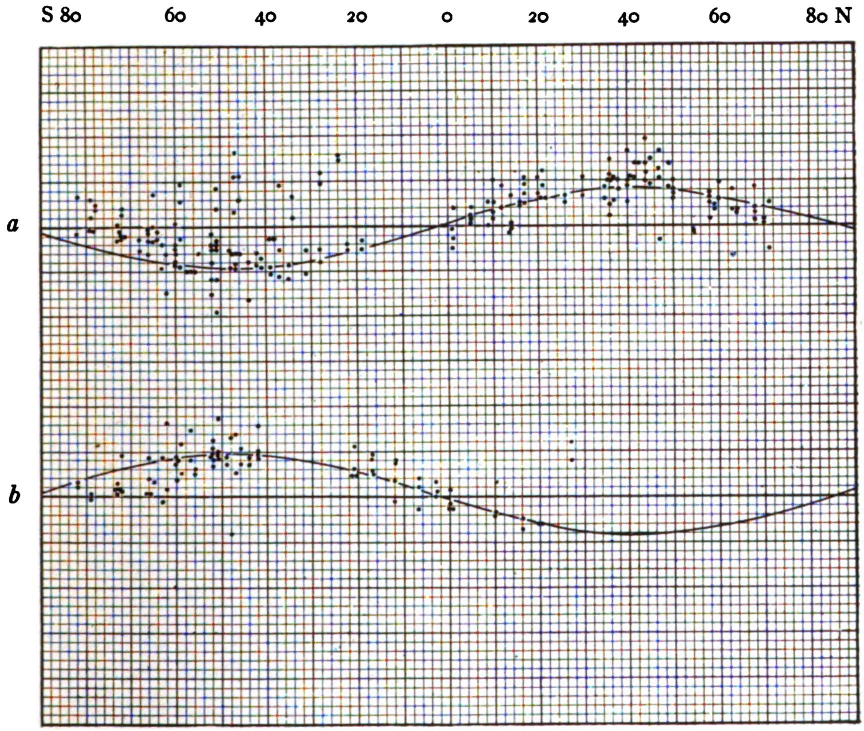


FIG. 5.—Displacements for the fourth series, $\lambda\lambda$ 5812 and 5828, measured by Mr. Van Maanen.

a, Quarter-wave plate in normal position; *b*, Quarter-wave plate in inverted position.

Vertical scale: 1 division = 0.001 mm.

The evidence would thus appear to be conclusive that, within the precision of measurement, the sign of the displacement is reversed by inverting the quarter-wave plate. As atmospheric lines fail to show this effect, it cannot be considered of nstrumental origin. Furthermore, many solar lines do not share in the displacements. We are thus led to the conclusion that the cause

of the displacements is a magnetic field of sufficient strength to produce the observed displacements of λ 5912, λ 5828, and λ 5930, but too weak at certain other levels in the solar atmosphere to affect the lines which represent them.

The analogy afforded by sun-spots, where I have found a rapid decrease in the strength of the field in passing from low to high levels,[1] suggests that we are concerned with a low-level phenomenon. This view is supported, especially in the case of λ 5812 and λ 5828 by the results of Mr. St. John's recent investigations, which show that, in general, the fainter lines of the solar spectrum represent the lower levels. Another check is afforded by some measures made for me by Mr. Adams, who finds the following displacements at the sun's limb for the three lines in question:

λ 5812	0.012 Ångström
λ 5828	0.011
λ 5930	0.011

In his investigation on the displacements of lines at the sun's limb, Mr. Adams concluded that the displacements are largest for the elements which lie at the lowest levels in the sun's atmosphere.[2] Since the displacements given above are large for this region of the spectrum, we may conclude that the lines in question are probably produced at low levels. It should be noted, however, that other solar lines, showing equally large displacements at the limb, apparently give no evidence of the Zeeman effect. Mr. St. John will soon test this point further by a direct determination of the pressure displacements.

HYPOTHESIS OF LOCAL WHIRLS

The evidence presented above seems sufficient to prove that the observed displacements are caused by magnetic fields in the sun. We may next consider whether these fields are due to local phenomena or represent the magnetic effect of a rotating sphere. We know that sun-spots always show the Zeeman effect, and that

[1] *Contributions from the Mount Wilson Solar Observatory*, No. 30, p. 15; *Astrophysical Journal*, **28**, 329, 1908.

[2] *Contributions from the Mount Wilson Solar Observatory*, No. 43, p. 25; *Astrophysical Journal*, **31**, 30, 1910.

the widening of the lines frequently extends beyond the boundary of the penumbra. Magnetic fields may also be caused by invisible spots or by whirls in which no umbrae or penumbrae have appeared, if we may judge from the structure frequently presented by the H_α flocculi. Finally, there is some evidence to support the view that the pores are small vortices, which develop into spots under favorable conditions. Is it possible that the observed displacements are due to any of these causes?

I believe that we may answer this question without hesitation in the negative for the following reasons:

1. Our observations of sun-spots indicate that right-handed and left-handed whirls are about equally common in the northern and southern hemispheres. The great majority of spots consist of two principal members, frequently attended by satellites, the line joining the chief spots usually making a small angle with the solar equator. In general, I find these groups to be of the bipolar type, i.e., the two principal spots are of opposite polarity. When a new spot appears, it is very frequently double, and of the bipolar type. Hence there is no reason to suppose that the influence of spots, visible or invisible, incipient or disintegrating, could be of such a character as to produce Zeeman displacements which, on the average, are of opposite sign in the northern and southern hemispheres.

2. The observations have been made during a low minimum of solar activity, and in the great majority of cases no spots whatever, and few K_2 flocculi, were visible on the sun.

3. If the pores are electric vortices, like the spots, there is no reason to suppose that pores of one polarity preponderate in the northern hemisphere, and those of opposite polarity in the southern.

4. Even if there were a clear preponderance of pores of opposite sign north and south of the equator, it would be difficult to account for such a curve of displacements as the plotted observations represent.

5. Assuming, however, that such a curve could be plausibly explained as originating in the pores, it is evident from the character of the curve that we should be dealing with a general magnetic field of the sun, though not one caused by the solar rotation.

Although it is very improbable that the general curve of displacements is due to local vortices, we may expect to find irregularities in the curve when spots or other local fields lie on the slit. It is doubtful, however, whether any displacements of the wrong sign in the present investigation can be ascribed to such causes, though an exceptional number of discordant observations on June 3 and 4 may possibly be due to the proximity of a large K_2 flocculus. As the sun becomes more active, the effect of local perturbations will doubtless increase. A method of detecting them, which may prove to be useful, is to compare the area of the flocculi within a square, say, 10° on a side, centered on the slit, with the average deviation from the mean of the observed displacement.

THEORETICAL CURVE OF DISPLACEMENTS

The general expression for the displacement of a normal Zeeman triplet originating a source lying in the general magnetic field of the sun, here assumed to be a spherical magnet, is[1]

$$k\Delta = \epsilon \cos \gamma'. \tag{1}$$

The factor ϵ in the right-hand member of this equation represents the effect of the elliptical polarization produced by reflection from the silvered surfaces of the coelostat mirrors, while $\cos \gamma'$ is a function of the heliocentric latitude of the point observed, the deviation of the observer from the plane of the sun's equator, and the sun's magnetic elements. As previously stated, the effect of the mirror polarization is only to flatten the curve. The numerical values of ϵ corresponding to different values of the hour angle and declination may be seen by a reference to the table on p. 25 of Mr. Seares's paper. As the factor ϵ is nearly unity for normal observing conditions, we may disregard it for the present and consider only the quantity $\cos \gamma'$. The expression for this is

$$\begin{aligned} \cos \gamma' = & \{3 \sin (2\phi - D) + \sin D\} \cos i + \\ & \{3 \cos (2\phi - D) + \cos D\} \sin i \cos \lambda \end{aligned} \tag{2}$$

[1] The complete series of formulae derived by Mr. Seares, superintendent of the Computing Division, for the reduction of observations of the sun's general field, may be found in "The Displacement Curve of the Sun's General Magnetic Field," *Contributions from the Mount Wilson Solar Observatory*, No. 72; *Astrophysical Journal*, **38**, 99, 1913.

in which

ϕ = heliographic latitude of point observed,
D = heliographic latitude of sun's center,
i = inclination of magnetic axis to solar axis of rotation,
λ = longitude of north magnetic pole measured west from central meridian.

The observations show that i must be small, if not actually equal to zero, and for a preliminary comparison of the observations with the theory, we assume $i=0$. We therefore write

$$k\Delta = 3 \sin(2\phi - D) + \sin D. \tag{3}$$

The quantity k is a constant depending upon the units involved, the Zeeman separation of the line observed, and the sun's equatorial field-strength.

Since D is small, never exceeding $7°$, it follows that Δ is very nearly proportional to $\sin 2\phi$; and to the degree of approximation expressed by (3), the theoretical displacement-curve is that of $3 \sin 2\phi$ displaced laterally by the amount $\frac{1}{2} D$ and vertically by $\sin D$. These shifts are so small that they might well have been disregarded, but as they are easily included, they were taken into account in drawing the curves. This was possible, since the observations for the various series cover intervals of time so short that D may be regarded as constant for any given series.

Owing to the fact that the sun's field-strength and the Zeeman separations for the lines observed are at present unknown, it is necessary to determine the constant k from the observations themselves.

For numerically equal latitudes north and south we easily find from (3)

$$k = \frac{6 \sin 2\phi \cos D}{\Delta_n - \Delta_s} \tag{4}$$

which may be used for the determination of k. Equation (4) is most satisfactorily employed for latitudes near $45°$, and it is quite sufficient to write $\cos D = 1$.

The curves resulting from (3) and (4) corresponding to the various series of observations are shown in Figs. 2–6, together with the observations themselves. Owing to the systematic difference

between Miss Lasby and Mr. Van Maanen it was necessary to treat their results separately, and in general the displacements for each line have been considered separately for the different series. In the case of the first and third series, however, Mr. Van Maanen's results for λ 5930 have been combined for the determination of k, as an inspection of the plotted displacements showed that the values of the constant would be sensibly the same. A similar procedure was followed with $\lambda\lambda$ 5812 and 5828 in the second series.

Generally speaking, the agreement with the theory is as good as can be expected, in view of the large accidental errors of observation. There is a small irregularity in Mr. Van Maanen's results on λ 5930 for the first series (Fig. 2, *e*), but this apparently is to be attributed to the difficulties of measurement and the lack of extended experience in the use of the parallel plate micrometer, for Miss Lasby's measures of the same plates show a close agreement with the theoretical curve (Fig. 2, *d*). The results for the fourth series (Figs. 5 and 6) are of special interest, as they are more widely distributed in latitude than any of the others.

The observations of the first three series were confined to the latitudes N. 60°–S. 60°. Displacements having been found for the lower latitudes, it was desirable to make tests near the poles. For work in this region a large solar image is necessary, as the group of strips of the compound quarter-wave plate included in the measurement of the displacement for a single latitude cover at least 8 mm on the central meridian, and with a small solar image the change in latitude is too rapid to permit the four or more sets of measures to be combined satisfactorily. The 43-cm image, however, is large enough for study in very high latitudes, and accordingly a fourth series of observations was undertaken as a rigorous test of the validity of the conclusion that the displacements are due to the sun's general field. The results indicate clearly the decrease in the displacement with increasing latitudes beyond $\phi=45°$, and its approach to zero values at points near the poles. The close conformity with the theoretical curve is very satisfactory.

With regard to the theoretical expression for the displacement-curve, it may be remarked that, although developed primarily

for the case of a normal Zeeman triplet, it holds also for lines of more complicated structure including a single group of p-components, provided that the total intensity of the n-components

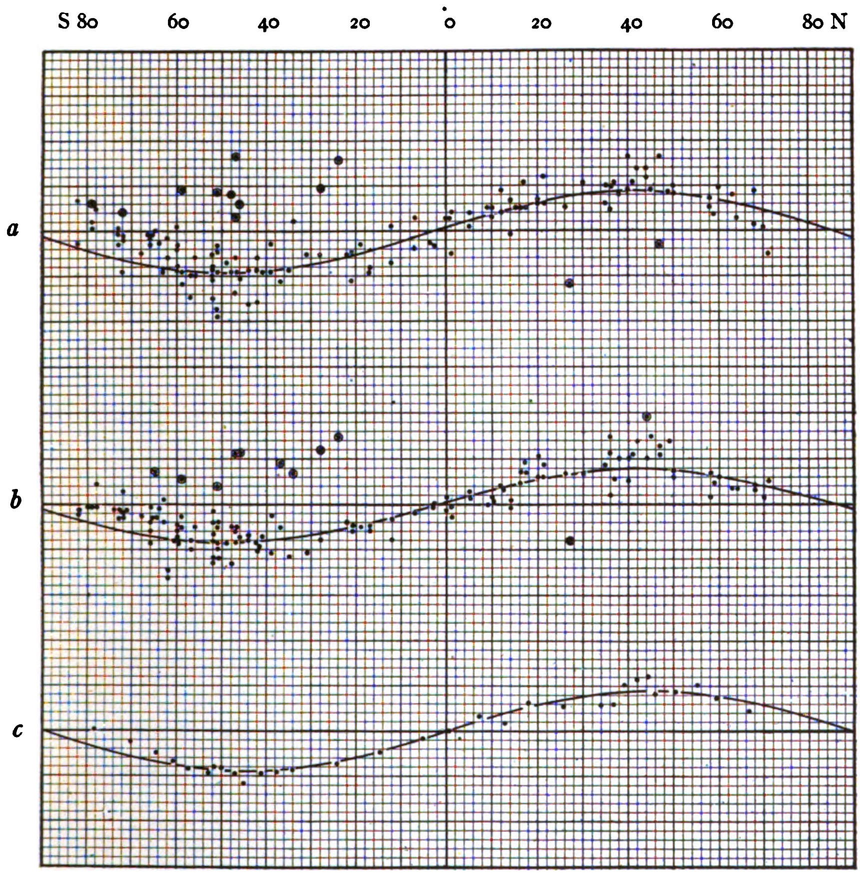


FIG. 6.—Displacements for the fourth series and mean curve

a, λ 5812; b, λ 5828; c, Mean curve of displacements including λ 5930 from first and third series and $\lambda\lambda$ 5812 and 5828 from fourth series. Measures by Mr. Van Maanen.

Vertical Scale: 1 division = 0.001 mm.

perpendicular to the field is the same as that of the p-components, and that the intensity distribution in the groups of n- and p-components is symmetrical with respect to the centers of the groups.

Although these conditions may not be rigorously fulfilled, laboratory results indicate that for many complex lines the approximation probably will be sufficient.

In grouping the results for the derivation of the values of k the question arose as to what should be the basis for the rejection of discordant observations—should obviously discordant plates, such as Nos. 26 and 27, be rejected as a whole, or should only those latitudes showing excessive deviations be excluded? Owing to the difficulty of establishing a satisfactory criterion for the rejection of plates, the latter alternative was adopted. The rejection in forming k was guided by a preliminary investigation of the average deviation from the mean curve defined by the observations themselves. A subsequent examination of the deviations from the theoretical curves showed, however, that the rejection was in each instance justified.

Table XII gives in a collected form the average deviations from the theoretical curves, first, on the basis of all of the material, and second, after the exclusion of certain results. Here the rejection was by Peirce's criterion, the limit being fixed by the average deviations based on all of the observed displacements. The discordant values thus found are indicated by parentheses in Tables IV–IX and by circles inclosing the points in the figures. The systematic difference between Miss Lasby and Mr. Van Maanen leads occasionally to an apparent contradiction, as, for example, in the case of latitude S. 56°, Table VI. The smaller of two positive displacements is rejected while the larger is retained. The corresponding deviations, however, are +11 and +7.8, one of which lies above the rejection limit, while the other is below it.

Table XII also gives, in the third and fourth columns, the values of the ordinates of the curves for $\phi=45°$, which are connected with k by the relation $\Delta_{45}=3/k$. These exhibit numerically the systematic differences in the various results.

For those cases in which the displacement of the curve due to the deviation of the observer from the sun's equator has been included, the values are the means of the maximum ordinates north and south, and, strictly speaking, do not correspond accurately to 45°. The zero value of the ordinate at 45° for λ 5930

in the second series is a numerical expression of the fact that this particular series shows no appreciable variation of the displacement with the latitude. The deviations in this case are referred directly to the axis, and the mean deviation is of course the average of the observed displacements without regard to sign.

The general consistency of the material is illustrated by the fact that out of 766 values only 62 are sufficiently discordant to call for rejection. These numbers do not include the measures on λ 5930 in the second series; the measures by Miss Lasby and Mr. Van Maanen in the first series have been counted as separate observations.

TABLE XII

VALUES OF DISPLACEMENT AT $\phi=45°$ AND AVERAGE DEVIATIONS

Series	λ	Δ at 45°		Miss Lasby					Mr. Van Maanen				
		L.	V. M.	All Observations		No. Rejected	Revised		All Observations		No. Rejected	Revised	
				Av. D.	No. Obs		Av. D.	No. Obs.	Av. D.	No. Obs.		Av. D.	No. Obs.
I	5812	10.3	8.6	8.8	28	6	3.6	22	2.6	28	3	2.6	25
	5828	10.3	6.7						3.7	39	2	3.7	37
	5930	9.7	5.3	3.4	75	4	2.6	71	3.5	102	8	2.8	94
II	5812	..	4.0	..	..	..	..	..	4.1	42	3	3.5	39
	5828	..	4.0	..	..	..	..	..	3.8	42	4	2.8	38
	5930	..	0.0	..	..	..	..	..	3.4	90	..	..	..
III	5930	..	5.3	..	..	..	..	..	4.0	135	9	3.4	126
IV	5812	..	4.4	..	..	..	..	..	1.9	137	12	1.3	125
	5828	..	4.0	..	..	..	..	..	1.7	138	11	1.2	127

It is obviously useless to attempt any combination of the results into a final mean curve until the question of systematic errors shall have been investigated. It is, nevertheless, of interest to consider the mean curve defined by the measures by Mr. Van Maanen on λ 5930 in the first and third series and on $\lambda\lambda$ 5812 and 5828 in the fourth series, for all of which the systematic differences are small. The displacements (excluding those in parentheses) were arranged in order of decreasing latitude and combined into the normal points shown in Table XIII. The agreement of these

with the theoretical curve determined by the average of the ordinates at 45° for the four curves is shown in Fig. 6, *c*.

With the completion of the measures of λλ 5812 and 5828 on the plates of the fourth series, a search for other lines showing displacements was undertaken by Mr. Van Maanen. The results for the nickel line λ 5831 given in Table II suggested the desirability of systematic measures on this line. This was rendered the more important by the fact that in the meantime Mr. Babcock had succeeded in obtaining in the laboratory a value of the Zeeman

TABLE XIII

MEAN DISPLACEMENTS FROM λ 5930, FIRST AND THIRD SERIES, AND λλ 5812 AND 5828, FOURTH SERIES

Measures by Mr. Van Maanen. Unit=0.001 mm

Lat.	Δ	No. Obs.	Lat.	Δ	No. Obs.
N 68°8	+2.2	15	S 5°1	−0.8	15
59.4	+3.6	15	14.3	−2.4	15
55.4	+5.1	16	24.2	−3.6	15
50.3	+4.4	15	34.1	−4.3	15
46.1	+4.1	15	37.7	−4.6	15
44.5	+6.0	15	41.0	−4.7	15
41.9	+5.7	15	45.1	−5.8	16
39.3	+5.1	15	47.1	−4.7	15
36.7	+3.0	15	49.9	−4.1	15
33.9	+2.9	15	51.7	−4.1	15
25.7	+2.7	15	52.8	−4.7	15
18.0	+3.1	16	57.3	−4.1	15
12.7	+0.8	15	60.5	−3.5	15
7.3	+1.6	15	64.5	−2.5	15
N 0.5	0.0	15	70.0	−1.1	15
			S 78.1	+0.1	15

separation for the line in question. Mr. Van Maanen accordingly turned his attention to λ 5831 and has measured all of the plates of the fourth series except Nos. 279*b* and 280*a*, which showed serious discordances in the case of λλ 5812 and 5828. Although it is not feasible to include the detailed numerical results in this paper, a graphical representation of the measured displacements, about 120 in all, is shown in Fig. 7. The maximum displacement at 45° is obviously smaller than that found for the other three lines, but the reversal of sign in passing from one hemisphere to the other is clearly indicated.

SIGN OF THE DOMINANT CHARGE AND POLARITY OF THE SUN

We have seen that within the limits of precision, the observations agree satisfactorily with the curve representing the displacements of a normal Zeeman triplet originating in a source on the surface of a magnetized sphere, and observed from a point in or near the plane of its equator. The curve is approximate, since it takes no account (1) of possible deviations from the conditions presupposed in the development of the theoretical curve; (2) of the elliptical polarization produced by the coelostat mirrors; (3) of the fact that the field is too weak to produce complete separation of the components, thus involving abnormal Zeeman effects;[1]

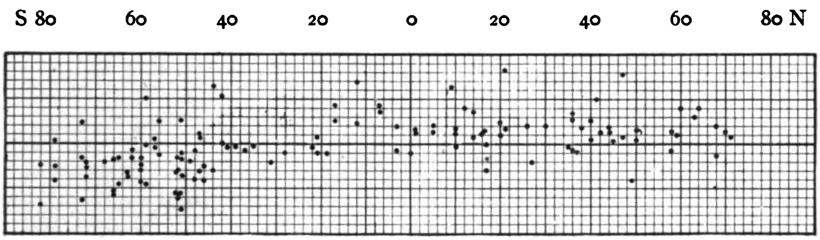


FIG. 7.—Displacements for λ 5831 from the fourth series. Measures by Mr. Van Maanen. Vertical scale: 1 division = 0.001 mm.

(4) of the possible lack of coincidence of the magnetic poles with the poles of rotation. Further, it is assumed that the spectrograph polarization is eliminated from the displacement, which apparently must be the case unless there is a wide divergence from the conditions referred to under (1). It may be shown, however, that the errors arising from these sources would be too small to be appreciable in the case of observations of the present degree of precision. Thus the results are in harmony with the conclusion that the sun is a magnetized sphere.

Disregarding, for the reasons already stated, the hypothesis of local whirls, we are led to seek the source of the sun's magnetism in its axial rotation. We may first inquire as to the sign of the dominant charge, on the assumption that the field is due to the

[1] Zeeman, "The Magnetic Separation of Absorption Lines in Connection with Sun-Spot Spectra. I," *Proc. Royal Academy of Sciences of Amsterdam*, meetings of January 29 and February 26, 1910.

rotation of a charged body or a body composed of neutral molecules which act as though they carried a charge. The observations show that in the northern hemisphere the light of the violet component of the line widened by the field is circularly polarized in the right-handed direction. In looking at the north pole of the sun, the direction of the solar rotation is left-handed. As pointed out by König and Cornu, the violet component of a magnetic doublet, observed in the direction of the lines of force (current flowing right-handedly through the coils of the magnet), is circularly polarized in the right-handed direction. Hence the sign of the dominant solar charge would be negative (opposite to that of the current through the magnet), and the polarity of the sun must correspond with that of the earth. Thus the north magnetic pole of the sun lies at or near the north pole of rotation.

STRENGTH OF THE SUN'S FIELD

In seeking to determine the strength of the sun's magnetic field, we are handicapped by the fact that the lines measured in this investigation are so weak in the arc and the spark that their Zeeman separations can be measured only with the greatest difficulty, or not at all. Repeated trials with λ 5929.898 have failed completely to show the line in the laboratory spectrum. The fainter line λ 5812.139, also identified by Rowland with iron, has likewise given great difficulty, but Mr. Babcock has finally succeeded in obtaining two plates showing measurable Zeeman separations. This fact, together with the different behavior of the two lines in sun-spot spectra renders it practically certain that the identification of λ 5929.898 with iron is erroneous. For the present, however, we may take advantage of the fact that the line appears as a doublet on some of our photographs of the sun-spot spectrum.

Table XIV contains data obtained by Mr. Babcock from a spot spectrum plate of excellent quality, No. T 190 *N*, taken on September 10, 1908, with a Fresnel rhomb and Nicol prism (in two positions of the latter). The fourth and fifth columns give the number of components and the multiple of the normal interval corresponding to each of several lines showing Zeeman separations.

The sixth column contains the measured separation from the normal position, and the last column, the field-strength of the spot in gausses calculated from the results of Mr. King's laboratory investigation of the Zeeman effect. The field-strength shows a marked variation with the intensity of the lines, but as the mean intensity of the comparison lines is approximately the same as that of λ 5929.898, we may accept provisionally $\Delta\lambda = \pm 0.038$ Ångström as corresponding to $H = 1066$ gausses. This result is, however, affected by a large uncertainty. Mr. St. John has shown that, although in general, intensity is a measure of level, there are, nevertheless, considerable differences for lines of the same intensity belonging to

TABLE XIV

ZEEMAN SEPARATIONS OF LINES IN SUN-SPOT SPECTRUM

λ (Rowland)	Element	Intensity in Sun	No. Components	$\frac{\Delta\lambda}{a\,\lambda^2}$	$\Delta\lambda$ Spot	Weight	H Spot
5918.773	*Ti*	0	3	3	±0.055Å	3	1090
5929.898	*Fe*	2	..	...	0.038	..	....
5930.406	*Fe*	6	3?	2+	0.028	1	760
5941.985	*Ti*	∞	6	2	0.043	2	1390
5966.055	*Ti, A*?	2	3	2	0.024	1	710
5985.040	*Fe*	6	3	2.5	0.038	2	920
6039.953	*V*	0	4	3	0.052	3	1050
6064.853	*Ti*	∞	3	4	0.088	3	1330
6065.709	*Fe*	7	3	1.4	±0.014	1	560
Weighted mean field-strength of spot.............................1066							

different elements. As the identification of λ 5930 with iron is probably incorrect, we have no assurance that the line in question originates at the mean level of the comparison lines listed in Table XIV.

It may be shown that the polar field-strength of the sun is

$$H_p = \frac{2\Delta_{45}}{3c}$$

in which Δ_{45} is the mean relative displacement in adjacent spectrum strips for $\phi = 45°$ north and south, and c the Zeeman separation of the line observed for a field of 1 gauss. From the above data we find for λ 5930, $c = 0.000036$ Ångström. The mean of the values of Δ_{45} found by Miss Lasby and Mr. Van Maanen for λ 5930

is 0.0075 mm=0.0015 Ångström (see Table XII). Substituting these quantities into the above expression, we find for the field-strength of the sun at its pole 28 gausses.

Turning now to $\lambda\lambda$ 5812 and 5831, the laboratory results are:

λ	$\Delta\lambda$	H	$\frac{\Delta\lambda}{a\lambda^2}$	C	Weight
5812	±0.064 Å	4000 gausses	1.0	0.000016 Å	1
	0.062	6500	0.6	0.000010	3
5831	0.320 } 0.300 }	22800	0.85	0.0000136	5

Mr. Van Maanen's measures on λ 5812 (see Table XII) give Δ_{45}=0.0042 mm=0.00086 Å., and, as a first approximation for λ 5831 (Fig. 7), Δ_{45}=0.003 mm=0.0006 Å. These lead respectively to values of 48 and 29 gausses for H_p. To make these results comparable with that of 28 gausses derived from λ 5930, they should be increased by about 60 per cent, on account of the systematic difference between Miss Lasby and Mr. Van Maanen.

The value from λ 5930 is based upon the assumption that the mean of the comparison lines corresponds to the same level in the spot as λ 5930, which probably is not the case. In view of the approximate value of Δ_{45} for λ 5831, the results for this line and λ 5812 are not necessarily discordant; but all three values are uncertain because of the unknown systematic error of measurement. Both $\lambda\lambda$ 5812 and 5831 appear to be lines of complex structure, but this can scarcely have affected the values of H_p, for substantially the same results are obtained by using the displacements for $\phi=35°$. At this point Δ is practically independent of the structure of the line. Disregarding the systematic error of measurement, the results indicate that the field-strength at the sun's pole is of the order of 50 gausses.

As already remarked (p. 80), the three lines on which attention has been concentrated in this preliminary investigation are probably produced at a comparatively low level. These clearly show the effect of the sun's field, while various higher level lines, promising from the laboratory standpoint, have hitherto failed to do so (see Table I, p. 40). Thus it is probable that the intensity

of the general field falls off very rapidly in passing upward through the reversing layer. It thus presents an interesting resemblance to the field in sun-spots, though the few data now available indicate that the decrease is much more rapid in the case of the general field.

IONIZATION IN THE SUN

As serious objections have been urged against all theories of terrestrial magnetism, it is hardly to be hoped that any one of them can be applied without modification to the sun, especially in view of its high temperature, low density, and gaseous condition. In the case of sun-spots, neutral molecules cannot produce the observed fields unless an improbable degree of centrifugal separation of the positive and negative electrons is assumed. However, an important investigation by Harker seems to be directly applicable here.

Two carbon electrodes were mounted within a carbon resistance furnace 5 mm apart, and connected externally with a galvanometer. At atmospheric pressure and a temperature of 2500° C., a current of nearly 2 amperes was observed when one electrode was cooled by temporarily removing it from the hot part of the furnace. The cooler electrode, on which much carbon was deposited, was the positive one.[1] As it has been shown by Fowler and by Adams, Gale, and myself that the vapors in sun-spots are cooler than those of the surrounding atmosphere, a flow of negative electrons should therefore take place on all sides toward the umbra. These, whirled in the vortex, may account for the strong magnetic fields observed. Perhaps the exquisite structure of the penumbra may also be due in part to the effect of the field on the moving electrons and in part to electrostatic phenomena. Harker's investigation shows that strong ionization currents, increasing with the temperature, can occur at atmospheric pressure. Mr. King has recently extended this work to higher pressures, with the following results: (1) the ionization current decreases as the pressure increases; (2) the decrease is rapid up to a pressure of four atmospheres; (3) the current is appreciable at high pressures (at least up to 20 atmospheres).

[1] Harker, "Very High Temperatures," *Nature*, July 18, 1912, p. 517.

On account of the greater mobility of the negative electrons, their tendency to flow toward regions of lower temperature, and the evidence afforded by Mr. King's experiments that solar ionization is not limited to the region of the pressure in and above the reversing layer, it is evident that the electrical and magnetic phenomena of the interior of the sun must differ radically from those of the earth. It may be remarked, however, that since the negative electrons will tend, on the average, to lie farther from the center of the sun than the positive electrons, the polarity of any general field that may thus result from the solar rotation should correspond with that of the earth's field.

In the solar atmosphere, as Arrhenius, Deslandres, and others have pointed out, we have every reason to suppose that the negative electrons lie farther from the photosphere, on the average, than the positive electrons. The rotation of the atmosphere with the sun would thus tend to set up a magnetic field, of the same polarity as that of the earth. At the base of the atmosphere this field would oppose the field due to the rotation of the body of the sun. Hence, assuming a suitable distribution of the positive and negative electrons, it may be possible to account in this way for the observed decrease in the strength of the general field at increasing distances from the photosphere. It may even turn out that the Zeeman effect observed is due to the rotation of the solar atmosphere and not to the rotation of the body of the sun.

It is evident, however, that such questions as these can be discussed to much better advantage after the strength of the general field at various levels has been measured. It will also be a matter of great interest and importance to determine whether the strength of the field undergoes appreciable variation during the sun-spot period, in harmony with the changes of solar activity. The work will be carried forward by Mr. Ellerman, Mr. Van Maanen, and myself, under an enlarged program which provides for the inclusion of lines representing a wide range of level, the investigation of systematic errors and new methods of measurement, and the study of allied solar and laboratory problems.

The work described in the present paper has been done during a period when I have been able to devote comparatively little time

to research. I have been fortunate, however, in having the cordial co-operation and assistance of several members of the Observatory staff, for which I am heartily indebted. The earlier photographs of the first series were taken by myself with the assistance of Mr. Ellerman, but most of the subsequent ones of all four series are due to the persistent and most efficient work of Mr. Ellerman alone. Mr. Kohlschütter also made a number of excellent plates. In the measurements, as the results show, the skill and experience of Miss Lasby proved to be a factor of the first importance. The measurement of the plates of all four series by Mr. Van Maanen has been carried out with great skill and unflagging interest. I am also indebted to Mr. Adams for valuable check measures, and to Mr. Kohlschütter, Miss Burwell, Miss Sheldon, Miss High, and Miss Ware for much work of measurement and computation. Mr. Seares has given me invaluable aid, which I greatly appreciate, both in the supervision of measurements and reductions, and in the preparation of this paper for the press. The important reduction formulae which he has derived are published in *Contributions from Mount Wilson Observatory*, No. 72. Mr. Babcock has rendered much assistance in the preparation of polarizing apparatus, the study of weak fields and other laboratory problems, and in connection with the work of measurement. I owe to Mr. King the results of his investigations of ionization currents at high pressures. I have also had the benefit of Dr. Anderson's aid and advice in several phases of the work.

I wish to express my thanks to Professor Schuster, Professor Zeeman, and Dr. Bauer for criticisms and suggestions based on their studies of magnetic phenomena, and to M. Cotton for valuable assistance in the design and construction of the polarizing apparatus for the 75-foot spectrograph.

DIFFICULTIES AND OBJECTIONS

The evidence presented above seems to indicate pretty conclusively that the sun possesses a general magnetic field of sufficient strength to produce the Zeeman effect in certain lines. Nevertheless, the difficulties and objections in the way of accepting such a conclusion must be recognized. The most important of these are as follows:

1. The small number of lines for which a clearly defined displacement has been established.

2. Observations of the center and limb, which afford a comparatively reliable test of level, do not indicate appreciable differences of level between the three lines observed and other lines showing apparently no displacement.

3. Two series of second-order plates for λ 5930 measured by Mr. Van Maanen fail to show the displacement found by him on other series of plates.

4. Measures of the first series by other observers fail to show the displacements found by both Miss Lasby and Mr. Van Maanen.

None of these appear to be insuperable. The evidence indicates that we are dealing with a low-level phenomenon, which implies that, generally speaking, only the fainter lines can be expected to show the displacements observed in the case of $\lambda\lambda$ 5812, 5828, 5831, and 5930. Furthermore, the quantities involved are so small that for lines of average Zeeman separation extended series of observations will be required to establish clearly the displacement. Casual measures on lines apparently promising are very likely to give negative or contradictory results. Moreover, no systematic search has yet been made for additional lines. The difficulties of measurement are so great that it seemed best to establish the reality of the effect for the lines here discussed before proceeding to a detailed examination of others.

The absence of displacements for lines shown by center and limb measures to be of the same order of level as $\lambda\lambda$ 5812, 5828, and 5930 may be due either to small Zeeman separations or to a rapid falling off in the field-strength with increasing elevation.

The difficulty experienced in the case of the second-order plates has already been discussed and possible explanations have been suggested. It cannot be said, however, that these appear to be adequate. Finally, the discordant results by various observers for the first series (including Mr. Van Maanen's first set of measures for this series) are reasonably accounted for on the basis of a lack of experience with measurements of the degree of difficulty involved, or of unfamiliarity with the instrument used.

SUMMARY

Fundamental considerations relating to the properties of matter indicate that all rotating bodies may give rise to magnetic fields. Although no theory has yet been found which completely accounts for the phenomena of terrestrial magnetism, it is probable that they result from the axial rotation of the earth. The sun, a great rotating body at a temperature which precludes the existence within it of permanent magnets, offers a means of testing the theory. The form of the corona and the motion of the prominences suggest that it is a magnet, but direct proof is lacking. An attempt was accordingly made to detect the Zeeman effect due to the general magnetic field of the sun.

Preliminary observations, made in 1908 with the 60-foot tower telescope, were inconclusive. The work was renewed with the 75-foot spectrograph of the 150-foot tower telescope in January 1912 and continued through the year, with the following results:

1. The lines λ 5812.139 (*Fe*, 0), λ 5828.097 (—, 0), λ 5831.821 (*Ni*, 1), and λ 5929.898 (*Fe*, 2) show distinct displacements not shared by atmospheric lines nor by certain other solar lines.

2. The sign of the displacements is reversed, in 77 per cent of the measures, when the quarter-wave plate, mounted above a Nicol prism over the slit of the spectrograph, is inverted.

3. The sign of the displacements is reversed when a half-wave plate, mounted between the quarter-wave plate and Nicol, is turned through an angle of 45°.

4. The sign of the displacements is opposite in the northern and southern hemispheres of the sun.

5. The maximum displacements are observed about 45° north and south of the solar equator. From this point they decrease to zero at the equator and near the poles of rotation.

6. A curve representing the displacements as a function of the latitude corresponds closely with a theoretical curve, showing the displacements of a normal Zeeman triplet observed at various latitudes in the field of a magnetized sphere.

7. In view of this agreement, and the apparent impossibility of accounting for the observed displacements on other grounds,

it is probable that they represent the Zeeman effect due to the sun's general magnetic field.

8. Assuming this to be true, we find that the magnetic poles of the sun lie at or near the poles of rotation.

9. The polarity of the sun corresponds with that of the earth, i.e., the north magnetic pole lies near the north heliographical pole.

10. On the hypothesis that the magnetism of the sun is due to the axial rotation of a body acting as though it carried a residual volume charge, the sign of the charge comes out negative.

11. The preliminary results indicate that the general magnetic field decreases rapidly in intensity at levels in the solar atmosphere higher than those represented by the lines named in paragraph 1.

12. A first approximate value for the vertical intensity of the sun's general field at the poles is 50 gausses.

MOUNT WILSON SOLAR OBSERVATORY
March 28, 1913

THE DISPLACEMENT-CURVE OF THE SUN'S GENERAL MAGNETIC FIELD[1]

By FREDERICK H. SEARES

In *Contributions from the Mount Wilson Solar Observatory*, No. 71, Mr. Hale has described the results of an investigation undertaken for the purpose of determining whether the sun possesses a general magnetic field similar to that surrounding the earth. The observational evidence seems clear. The spectrum lines observed with the 75-foot spectrograph and the polarizing apparatus of the 150-foot tower telescope show displacements that apparently cannot be attributed to any other cause. The displacement varies with the latitude, and the algebraic sign reverses in passing from one hemisphere to the other; but in order that there might be a more rigorous control of the results and their interpretation, it seemed advisable to compare the observed displacements with the theoretical displacement-curve derived on the assumption that the sun is a magnetized sphere. It was further desirable to have available formulae for determining the position of the magnetic axis relative to the axis of rotation. To satisfy these requirements the equation connecting the displacement of a spectrum line with the solar magnetic elements and the co-ordinates of the observer and the observed point was established. The following pages contain the development of this equation and an indication of its application to the determination of the position of the sun's magnetic axis. Owing to our imperfect knowledge of the electrodynamical theory underlying the structure of more complicated lines, the discussion will be restricted mainly to the case of the simple Zeeman triplet, although indications of possible extensions of the theory will be given.

Mr. Hale has fully described the instrumental equipment; but as what follows depends intimately upon the construction and operation of the polarizing apparatus, the essential features of this part of the instrument will be explained. It includes a Nicol prism

[1] *Contributions from the Mount Wilson Solar Observatory*, No. 72.

and a compound quarter-wave plate, placed immediately in front of the slit of the spectrograph. The quarter-wave plate consists of a series of mica strips mounted perpendicularly to the slit, with their edges in contact, between two glass plates. The optical axes of the strips are inclined at an angle of 45° to the slit, with the "fast" directions of adjacent strips perpendicular to each other. The Nicol is adjusted so that plane polarized light vibrating parallel to the slit is freely transmitted, while that vibrating perpendicularly to the slit is obstructed.

If, therefore, a beam of circularly polarized light be directed toward the slit of the spectrograph, it will be transformed by the mica strips of the quarter-wave plate into a series of plane polarized beams whose vibration planes are alternately parallel to and perpendicular to the slit. The Nicol transmits the former but not the latter. The slit will therefore be illuminated throughout 2 mm intervals with dark stretches of 2 mm intervening. If a beam circularly polarized in a direction opposite to that just considered be substituted, the illuminated portions will become dark, while the dark parts will receive light.

If now a luminous source situated in a magnetic field be examined in the direction of the lines of force, the slit will be illuminated throughout its length, owing to the presence of the opposite circular vibrations emitted by the outer components of the Zeeman triplets. The spectrum will be divided longitudinally into two groups of strips, alternately distributed, one of which will show the right, and the other the left components of the triplets. Under the conditions assumed, the p-components do not appear; any given strip contains radiation from but one of the n-components, and the displacement from the normal position of the line is proportional to the field-strength. It is the distribution of the radiation and the amount of the resultant displacement for the modified conditions occurring in solar observations that must be determined. The most important modification in such observations lies in the fact that the line of sight does not in general coincide in direction with the lines of force. The circular vibrations therefore enter the analyzer as elliptically polarized light, and, in addition, a portion of the linear vibrations from the midde

component also reaches the instrument. The action of the quarter-wave plate and the Nicol upon this mixture of elliptical and plane polarized light has now to be investigated.

Let γ represent the angle included between the line of sight and the lines of force cutting the sun's surface at the point observed. Viewed at this angle the opposite circular vibrations of the triplet may be represented by

$$\left.\begin{aligned} x&=a \sin \omega_1 t \\ y&=b \cos \omega_1 t \end{aligned}\right\} \tag{1}$$

$$\left.\begin{aligned} x&=a \sin \omega_2 t \\ y&=-b \cos \omega_2 t \end{aligned}\right\} \tag{2}$$

in which $b=a \cos \gamma$. The form of (1) and (2) assumes that the axes of x and y are perpendicular to the line of sight, and oriented so that OY lies in the plane defined by the line of sight and the lines of force. The elliptical vibration (1) is equivalent to the two opposite circular vibrations

$$\left.\begin{aligned} x_1&=\tfrac{1}{2}(a+b) \sin \omega_1 t \\ y_1&=\tfrac{1}{2}(a+b) \cos \omega_1 t \end{aligned}\right\} \tag{3}$$

$$\left.\begin{aligned} x_2&=\tfrac{1}{2}(a-b) \sin \omega_1 t \\ y_2&=-\tfrac{1}{2}(a-b) \cos \omega_1 t \end{aligned}\right\} \tag{4}$$

Owing to the fact that the slit is always placed parallel to the central solar meridian, the axes of x and y will not coincide with the directions of the optical axes of the quarter-wave plate. Let β be the angle through which the axes of x and y must be rotated in the positive (counter-clockwise) direction in order to bring them into coincidence with the optical axes of any given section of the quarter-wave plate. The vibrations (3) and (4) when referred to the latter axes become

$$\left.\begin{aligned} \xi_1&=\tfrac{1}{2}(a+b) \sin (\omega_1 t+\beta) \\ \eta_1&=\tfrac{1}{2}(a+b) \cos (\omega_1 t+\beta) \end{aligned}\right\} \tag{5}$$

$$\left.\begin{aligned} \xi_2&=\tfrac{1}{2}(a-b) \sin (\omega_1 t-\beta) \\ \eta_2&=-\tfrac{1}{2}(a-b) \cos (\omega_1 t-\beta) \end{aligned}\right\} \tag{6}$$

Equations (5) and (6) may be written at once by noting that the only effect of the rotation is to increase the phase of the negative (clockwise) circular vibration (3), and decrease that of the positive vibration (4), by the angle β.

The circular vibrations (5) and (6) are transformed by the quarter-wave plate into linear vibrations whose planes, with a proper orientation of the "fast" and "slow" directions of the plate, are respectively parallel to and perpendicular to the slit. If the direction of the slit be denoted by OY', the resulting linear vibrations will be

$$\left.\begin{aligned} x' &= \frac{1}{\sqrt{2}}(a-b)\cos(\omega_1 t-\beta-\delta_1) \\ y' &= \frac{1}{\sqrt{2}}(a+b)\cos(\omega_1 t+\beta-\delta_1) \end{aligned}\right\} \qquad (7)$$

The second elliptic vibration (2), gives a similar result, which is immediately derived from (7) by changing the sign of b and modifying the phase to correspond with the frequency ω_2. Thus,

$$\left.\begin{aligned} x' &= \frac{1}{\sqrt{2}}(a+b)\cos(\omega_2 t-\beta-\delta_2) \\ y' &= \frac{1}{\sqrt{2}}(a-b)\cos(\omega_2 t+\beta-\delta_2) \end{aligned}\right\} \qquad (8)$$

Consider now the linear vibrations emitted perpendicularly to the lines of force by the central component of the triplet. Since a is the amplitude of the original circular vibrations, that of the linear vibrations must be represented by $\sqrt{2}\,a$. Viewed at the angle γ the latter are therefore of the form

$$x=0, \quad y=\sqrt{2}\,a\sin\gamma\cos\omega t.$$

The components parallel to the optical axes of the strip previously considered are therefore

$$\begin{aligned} \xi &= \sqrt{2}\,a\sin\gamma\sin\beta\cos\omega t \\ \eta &= \sqrt{2}\,a\sin\gamma\cos\beta\cos\omega t \end{aligned}$$

Traversing the quarter-wave plate, these are transformed into the elliptic vibration

$$\begin{aligned} \xi &= -\sqrt{2}\,a\sin\gamma\sin\beta\sin(\omega t-\delta) \\ \eta &= \sqrt{2}\,a\sin\gamma\cos\beta\cos(\omega t-\delta) \end{aligned}$$

whose components perpendicular to and parallel to the slit are, respectively,

$$\left.\begin{aligned} x' &= -a\sin\gamma\cos(\omega t-\beta-\delta) \\ y' &= a\sin\gamma\cos(\omega t+\beta-\delta) \end{aligned}\right\} \qquad (9)$$

This result can also be derived directly from (7) by writing $a=0$, $b=\sqrt{2}\,a\sin\gamma$, and modifying the phase.

Equations (7), (8), and (9) represent the various types of vibration in the beam emerging from the mica strip of the quarter-wave plate. The results for an adjacent strip will be similar, but with an interchange in the x' and y' components. Each type corresponds to one of the three components of the triplet. As all vibrations parallel to the slit are transmitted by the Nicol, it appears that each type will be represented in the spectrum. Each spectrum strip will contain all three components, but with an alternation in the intensity distribution. For one set of alternate strips the intensities from violet to red will be

$$\tfrac{1}{2}(a+b)^2\,,\quad a^2\sin^2\gamma\,,\quad \tfrac{1}{2}(a-b)^2\,;$$

for the other,

$$\tfrac{1}{2}(a-b)^2\,,\quad a^2\sin^2\gamma\,,\quad \tfrac{1}{2}(a+b)^2\,.$$

Substituting the value $b=a\cos\gamma$, and assuming that the total intensity of the three components is unity, these expressions become

$$V=\tfrac{1}{4}(1-\cos\gamma)^2\,,\quad M=\tfrac{1}{2}\sin^2\gamma\,,\quad R=\tfrac{1}{4}(1+\cos\gamma)^2\,. \tag{10}$$

The separation is proportional to the field-strength, but in the case of weak magnetic fields the lines will not be resolved. Owing to the different intensities of the components, however, the resultant blend will not coincide with the normal position of the triplet; and as the displacement in adjacent strips is in opposite directions, it will still be possible to determine the amount of the separation. It is the relative displacement of the blended line for adjacent spectrum strips that Mr. Hale has observed.

The derivation of an expression for the resultant displacement requires a consideration of the way in which the three components unite to form the resultant. The intensity distribution in the three lines may be represented by

$$y_1=k_1f(x+\sigma)\,,\quad y_2=k_2f(x)\,,\quad y_3=k_3f(x-\sigma)\,, \tag{11}$$

in which σ is the separation of the outer components from the middle line. The constants k are independent of x, and we assume the functions f to be symmetrical with respect to the axis of y. The total intensities are therefore the integrals between $-\infty$ and $+\infty$ of the expressions (11). Since the definite integrals of $f(x+\sigma)$, $f(x)$, and $f(x-\sigma)$ are equal, it follows that the values of k are respectively

proportional to V, M, and R. Omitting the factor of proportionality, we may write

$$y_1 = Vf(x+\sigma) , \quad y_2 = Mf(x) , \quad y_3 = Rf(x-\sigma) . \tag{12}$$

The equation defining the intensity distribution of the blended line is therefore

$$Y = Vf(x+\sigma) + Mf(x) + Rf(x-\sigma) . \tag{13}$$

The question now arises as to what point of this line is to be regarded as determining its position. For a sharply defined maximum, there would undoubtedly be a tendency to make settings upon the maximum itself in any attempt to determine the position of the line. For a broad, diffuse line with a flat maximum, probably the center of gravity would be the determining point. The lines observed by Mr. Hale are of this latter character, but it will be shown that the result is essentially the same, whichever point be taken as measuring the displacement, as long as the separation σ is small as compared with the width of the line. This requirement, however, is satisfied in the case of observations of the sun's general field. For the lines used thus far, the ratio of separation to width is of the order of 0.01, and it will therefore be possible to simplify the discussion by disregarding the second and higher powers of σ.

Developing the first and third terms of (13) according to powers of σ and noting that by (10),

$$V+M+R=1 , \quad R-V=\cos\gamma , \tag{14}$$

we find

$$Y = f(x) - \sigma \cos\gamma f'(x) . \tag{15}$$

Equation (15) represents, however, the first two terms of a Taylor's series development, the remaining terms of which contain squares and higher powers of σ. We may therefore write

$$Y = f(x - \sigma \cos\gamma) . \tag{16}$$

To the degree of precision considered, the resultant line has therefore the same form as its components, and is symmetrical with respect to

$$x = \sigma \cos\gamma \tag{17}$$

as an axis. The co-ordinates of its maximum and center of gravity coincide and are determined by (17).

Since the relative displacement in adjacent strips of the spectrum is twice the displacement from the normal position, we have

$$\Delta = 2\sigma \cos\gamma . \tag{18}$$

It will be noted that the result is independent of the particular form of the intensity distribution. We have assumed merely that $f(x)$ is symmetrical, that it is developable for small values of x, and that σ is small as compared with the width of the lines. It appears at once from a consideration of the geometrical conditions of the problem that all of these are admissible. It will be observed further that the result is independent of the orientation of the slit, for it does not contain the angle β which defines this orientation.

We have now to evaluate the two factors in (18). The first depends upon the field-strength and the dispersion of the spectrograph. Assuming the distribution of the magnetic force over the sun's surface to be similar to that on the earth, its intensity at any magnetic latitude ϕ' will be[1]

$$H = H_e H' \tag{19}$$

in which H_e is the equatorial field-strength, and

$$H' = \sqrt{1+3\sin^2\phi'} . \tag{20}$$

We therefore have

$$\Delta = 2cH_e H' \cos\gamma \tag{21}$$

in which c is a constant determined by the units employed.

To determine the angle γ consider Fig. 1, and let it be recalled that the observations are always made with the slit in coincidence with the central meridian of the solar image.

The figure represents a projection of the various points involved on the surface of the celestial sphere, the center being at C. We have

P = sun's north pole.
P' = adjacent magnetic pole.
O = observed point, always on the central meridian PE.
E = intersection of central meridian with sun's equator.
E' = intersection of magnetic meridian through O with magnetic equator.

[1] Foster and Porter, "Electricity and Magnetism," 314, London, 1903.

S = intersection of line of sight with sphere.
F = intersection with sphere of tangent to line of force at observed point.
ϕ = EO = heliographic latitude of O.
ϕ' = $E'O$ = magnetic latitude of O.
D = ES = heliographic latitude of sun's center.
Q = angle at O between central meridian and magnetic meridian.
δ' = angle between sun's surface and line of force at observed point; $90-\delta'=FO$.

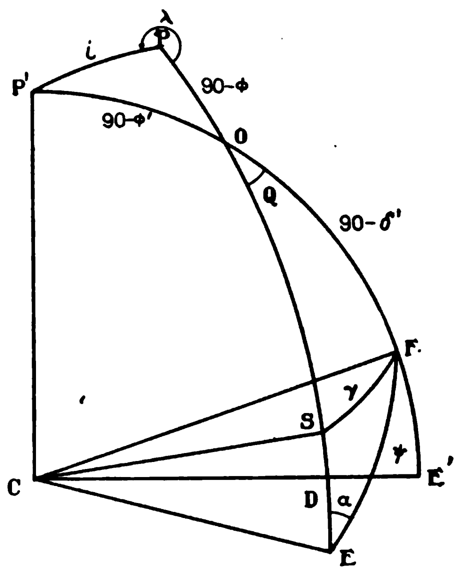


FIG. 1

γ = SF = angle between line of sight and line of force at observed point.
i = PP' = inclination of magnetic axis to solar axis of rotation.
λ = $\angle OPP'$ = longitude of magnetic pole referred to central meridian and measured in direction of sun's rotation.
ψ = $\angle ECF$ = arc EF.
α = $\angle SEF$.

The solution of the problem requires the expression of $H'\cos\gamma$ as a function of ϕ, D, λ, and i. From $\triangle$ ESF

$$\cos\gamma=\cos D\cos\psi+\sin D\sin\psi\cos\alpha\,. \qquad (22)$$

From $\triangle$ *EOF*

$$\left.\begin{aligned} \cos\psi &= \cos\phi\sin\delta' + \sin\phi\cos\delta'\cos Q \\ \sin\psi\cos\alpha &= \sin\phi\sin\delta' - \cos\phi\cos\delta'\cos Q \end{aligned}\right\} \tag{23}$$

The inclination of the lines of force to the sun's surface at the observed point is connected with the magnetic latitude by the relation[1]

$$\tan\delta' = 2\tan\phi' \tag{24}$$

whence we find

$$H'\sin\delta' = 2\sin\phi',\ H'\cos\delta' = \cos\phi' \tag{25}$$

in which H' has the value defined by (20).

Substituting (25) into (23)

$$\left.\begin{aligned} H'\cos\psi &= 2\cos\phi\sin\phi' + \sin\phi\cos\phi'\cos Q \\ H'\sin\psi\cos\alpha &= 2\sin\phi\sin\phi' - \cos\phi\cos\phi'\cos Q \end{aligned}\right\} \tag{26}$$

From $\triangle$ *OPP'*

$$\left.\begin{aligned} \sin\phi' &= L\sin\phi + M\cos\phi \\ \cos\phi'\cos Q &= L\cos\phi - M\sin\phi \end{aligned}\right\} \tag{27}$$

in which

$$L = \cos i,\ M = \sin i\cos\lambda. \tag{28}$$

The substitution of (27) into (26) gives

$$\left.\begin{aligned} 2H'\cos\psi &= 3L\ \sin 2\phi + 3M\cos 2\phi + M \\ 2H'\sin\psi\cos\alpha &= 3M\sin 2\phi - 3L\ \cos 2\phi + L \end{aligned}\right\} \tag{29}$$

Then, from the substitution of (29) into (23), we have

$$2H'\cos\gamma = 3L\sin(2\phi - D) + 3M\cos(2\phi - D) + L\sin D + M\cos D. \tag{30}$$

Combining (21) and (30) and restoring the values of L and M,

$$\left.\begin{aligned} k\Delta = &\{3\sin(2\phi - D) + \sin D\}\cos i + \\ &\{3\cos(2\phi - D) + \cos D\}\sin i\cos\lambda \end{aligned}\right\} \tag{31}$$

which is the required equation. The factor k is a new constant depending upon the units and the field-strength at the sun's magnetic equator.

Since the coefficients of $\cos i$ and $\sin i\cos\lambda$ in (31) may be replaced by expressions of the form $n\cos N$ and $n\sin N$ it appears that, whatever the values of D, i, and λ, the displacements always define a sine curve. But the latitude of the sun's center, D, is small, never exceeding 7°, and the observations show that i is also

[1] Foster and Porter, *loc. cit.*

small, if not actually zero. The displacement-curve is therefore approximately $3 \sin 2\phi$. Its ordinates are zero near the equator and the poles; they have opposite signs in the two hemispheres, and maximum absolute values near $\phi=45°$, north and south.

Equation (31) contains three unknowns, k, i, and λ. For their determination, consider first values of the displacements for numerically equal northern and southern latitudes, observed on or near the same date. The angle D will then be sensibly unchanged. Denoting the displacements by Δ_n and Δ_s, we find

$$k(\Delta_n-\Delta_s)=6 \sin 2\phi \ (\cos D \cos i+\sin D \sin i \cos \lambda) . \qquad (32)$$

The parenthesis in the right member of this expression differs from unity by a quantity of the second order in D and i, and it is quite sufficient to write

$$k=\frac{6 \sin 2\phi}{\Delta_n-\Delta_s} . \qquad (33)$$

The denominator has its maximum near $\phi=45°$, and the equation is most advantageously used for points near this latitude.

Writing now (31) in the form

$$k\Delta=A \cos i+B \sin i \cos \lambda , \qquad (34)$$

we have, with sufficient approximation,

$$\sin i \cos \lambda=\frac{k\Delta-A}{B} . \qquad (35)$$

The application of this expression should be restricted to points near the equator. If the values of $\sin i \cos \lambda$ derived from a series of observations extending over one or more revolutions of the sun be plotted with values of the time as abscissae, they will define a curve whose amplitude will be $\sin i$. The intersections of the curve with the axis will indicate the epochs when the longitude of the magnetic pole referred to the central meridian is 90° or 270°.

For the application of (35) it will be convenient to tabulate the values of A and B with the arguments ϕ and D; owing to the limitation of the equation to latitudes near the equator, the tables need not be extensive.

Equations (33) and (35) serve for the determination of k, i, and λ. Although the introduction of k affords a convenient arrangement of the formulae for the calculation of i and λ, we are really

interested in the value of the solar field-strength H_e upon which k depends.

By comparing (18) and (21), it appears that when Δ is expressed in Ångström units, c represents the separation in Ångströms of an n-component from the p-component of the line observed produced by a field of 1 gauss. When this quantity has been determined by appropriate laboratory investigations, the solar field-strength can be determined. For (21) may be written

$$\Delta = cH_eF \tag{36}$$

in which Δ is now supposed to be expressed in Ångströms, while F represents the right-hand member of (31). When i and λ have been found by the method outlined, H_e may be calculated by (36), or by an equation analogous to (32), namely

$$\Delta_n - \Delta_s = 3cH_p \sin 2\phi(\cos D \cos i + \sin D \sin i \cos \lambda)\,, \tag{37}$$

into which the polar field-strength $H_p = 2H_e$ has been introduced. For a first approximation we may write $i=0$, $\cos D = 1$; and applying (37) to $\phi = 45°$, we have for the polar field-strength

$$H_p = \frac{2\Delta_{45}}{3c} \tag{38}$$

in which Δ_{45} is the mean displacement at 45°.

Thus far it has been assumed that the line observed is a normal Zeeman triplet. It is obvious, however, that the applicability of the formulae is not restricted to lines of this character. For the n- and p-components of the normal triplet, we may substitute, throughout, the groups of n- and p-components of lines of more complicated structure. Certain conditions must, however, be fulfilled. For example, the total intensity of the n-components, when examined perpendicularly to the field, must equal that of the p-components. Further, the various groups of components considered as blended lines must possess an intensity distribution which is symmetrical with respect to the centers of the groups. Otherwise the preceding developments presuppose no conditions which in practice would not be fulfilled. It is impossible to indicate the percentage of lines satisfying these conditions, but probably the number is considerable.

If in any given case there is reason to suppose that one or more

of the above conditions is not fulfilled, it will still be possible to determine the strength of the solar field. It is only necessary to consider the displacement at that point of the solar surface for which the lines of the force are parallel to the line of sight. There the light received in the spectrum comes wholly from one of the *n*-components, and the relative displacement in adjacent strips is directly the Zeeman separation of the line. Since neither the *p*-component nor the second *n*-component enters, there is no question of relative intensities or of a resultant blend, and we are independent of the structure of the line. The condition of parallelism means that the points S and F in Fig. 1 must coincide, which can occur only when $\lambda=0°$ or $180°$; otherwise both S and F would have to coincide with O, which is an impossible condition, for $ES=D$ is restricted to values less than $7°$, while F can coincide with O only when O is at P'. Since, however, i is certainly small, we may substitute for the coincidence of S and F the condition $OS=OF$ or

$$90°-\delta'=\phi-D\,,$$

which will never be greatly in error, and indeed will be exact when $\lambda=0°$ or $180°$. By (24) this becomes

$$2\tan\phi'=\cot(\phi-D)\,. \tag{39}$$

As an approximation we may write $\phi'=\phi$, $D=0$, whence

$$\tan^2\phi=\tfrac{1}{2}\text{ or }\phi=35.^\circ 3\,.$$

Applying therefore equation (21) to this latitude we have simply

$$\Delta_{35}=2cH_eH'$$

from which, with the aid of (20)

$$H_p=\frac{\Delta_{35}}{\sqrt{2c}} \tag{40}$$

The preceding developments are complete in so far as they relate to the transformations taking place in the beam of light incident upon the quarter-wave plate. They disregard, however, the fact that the beam has undergone two reflections from the silvered surfaces of the coelostat mirrors before reaching the polarizing apparatus. These reflections modify the polarization produced in the solar lines by the sun's general field and presumably influence to some degree the observed displacements. Although Mr. Hale has

shown, by means of the polarimeter,[1] that under normal observing conditions the elliptical polarization introduced by the mirrors is small, it is of interest to consider the matter analytically. From the standpoint of a definite numerical determination, such an investigation cannot be regarded as complete, owing to the lack of specific information as to the optical constants of the reflecting surfaces. These probably vary within rather wide limits with increasing age of the silver coat. Nevertheless, the results for a normal silver surface should afford important indications as to the magnitude of the influence upon the displacements of the solar lines, and its variation with the changing conditions of observation.

Before proceeding to an examination of the modifications imposed upon the light-vibrations by the successive reflections and their subsequent passage through the polarizing apparatus, we shall consider the general results of metallic reflection. These are expressed by the equation[2]

$$\frac{R_p}{R_n}e^{i\Delta}=-\frac{I_p}{I_n}\frac{\cos(i+r)}{\cos(i-r)} \tag{41}$$

in which I and R represent the amplitudes of the incident and reflected vibrations. The subscripts p and n refer to directions respectively parallel to and perpendicular to the plane of incidence, and perpendicular to the direction of the incident or reflected ray, as the case may be. Δ is the excess of the change in phase produced by the reflection of the p-component over that of the n-component (not to be confused with the displacement Δ used above). In the left member i indicates the imaginary radical, while in the right, it is the angle of incidence. The angle r, analogous to the angle of refraction in the case of a transparent medium, must be replaced by the complex dielectric constant, which in turn is a function of the optical constants of the reflecting surface. Writing

$$\rho'=-e^{-i\Delta}\frac{\cos(i+r)}{\cos(i-r)}, \tag{42}$$

[1] *Contributions from Mount Wilson Solar Observatory*, No. 71; *Astrophysical Journal*, July, 1913.

[2] Drude, "Theory of Optics", translated by Mann and Millikan, 282, 361, 1902.

(41) may be replaced by the two equations

$$\left.\begin{aligned} R_p &= hI_p\rho' \\ R_n &= hI_n \end{aligned}\right\} \tag{43}$$

which are the relations connecting the incident and reflected amplitudes parallel to and perpendicular to the plane of incidence. Concerning the factor h we need not inquire further at the moment.

From (42) we may derive[1]

$$\frac{1+\rho' e^{i\Delta}}{1-\rho' e^{i\Delta}} = \cot P e^{iQ} . \tag{44}$$

P and Q are defined by

$$\left.\begin{aligned} \tan P &= \frac{n\sqrt{1+\kappa^2}}{\sin i \tan i} \\ \tan Q &= \kappa \end{aligned}\right\} \tag{45}$$

which connect ρ' and Δ with the optical constants n and κ.

Replacing in (44) the exponentials by the corresponding trigonometric functions and equating the real and imaginary parts of the resulting expression we find

$$\left.\begin{aligned} \rho' \sin \Delta &= \frac{\sin Q \sin 2P}{1+\cos Q \sin 2P} \\ \rho' \cos \Delta &= \frac{\cos 2P}{1+\cos Q \sin 2P} \end{aligned}\right\} \tag{46}$$

whence

$$\left.\begin{aligned} \tan \Delta &= \sin Q \tan 2P \\ \rho'^2 &= \frac{1-\cos Q \sin 2P}{1+\cos Q \sin 2P} \end{aligned}\right\} \tag{47}$$

By means of (45) the latter of these may be written

$$\rho'^2 = \frac{(\sin i \tan i - n)^2 + n^2\kappa^2}{(\sin i \tan i + n)^2 + n^2\kappa^2} . \tag{48}$$

An examination of (48) shows that for $i=0°$ or $90°$, $\rho'^2=1$; and that ρ'^2 has a minimum value of

$$\rho'^2 = \frac{\sqrt{1+\kappa^2}-1}{\sqrt{1+\kappa^2}+1}$$

[1] Drude, *op. cit.* pp. 361–64.

when

$$\sin i \tan i = n\sqrt{1+\kappa^2}, \tag{49}$$

that is, when i is equal to the principal angle of incidence. For all other values of i, ρ'^2 lies between these two limits. For normal silver and for sodium light the extinction coefficient κ, and the index n, have the values[1]

$$\kappa = 20, \quad n = 0.18.$$

The minimum value of ρ'^2 is therefore 0.9, and of ρ', 0.95. But these are attained only for the polarizing angle, which for silver, as may be found from (49), is approximately 75°. In practice, the angles of incidence will be much smaller than the polarizing angle and ρ' will differ but little from unity.

For the purposes of this investigation we may therefore replace (43) by

$$\left.\begin{aligned} R_p &= hI_p \\ R_n &= hI_n \end{aligned}\right\} \tag{50}$$

which will notably simplify the later discussion. Further, it appears from (45) that Q is approximately 87°. In consequence, we write $\sin Q = 1$, and find from (45) and (47)

$$\tan \tfrac{1}{2}\Delta = \frac{3.67}{\sin i \tan i} \tag{51}$$

Equations (50) and (51) are the relations defining the phenomena at the reflecting surfaces. We now turn to the application of these expressions to the problem under consideration.

In accordance with the previous notation the polarized vibrations incident upon the coelostat mirrors are of the form

$$\left.\begin{aligned} x &= a \sin \omega_1 t, & x &= 0 & x &= a \sin \omega_2 t \\ y &= b \cos \omega_1 t, & y &= \sqrt{2}a \sin \gamma \cos \omega t, & y &= -b \cos \omega_2 t \end{aligned}\right\} \tag{52}$$

in which $b = a \cos \gamma$; γ, as before, denotes the inclination of the line of sight to the lines of force cutting the solar surface at the point of observation. The first and last pair of equations in (52) represent the opposite circular vibrations of the outer components of the triplet, and the second pair the linear vibrations of the middle component. The axes to which (52) are referred are perpendicular

[1] Drude, *op cit.* p. 366.

to the first incident beam, with OY oriented in the direction of the central solar meridian.

These vibrations must now be followed through the successive reflections. It will be sufficient to develop the formulae for the first, as the results for the others can immediately be found by an appropriate change in the amplitude. For brevity the distinguishing subscript for the frequency ω will be omitted.

The course of the reflected beam is indicated by Fig. 2, which is in the form of a projection of the celestial sphere on the plane of the horizon. C is the center of the sphere; CMS', the meridian; P, the north pole; WME, the celestial equator; and S, the sun whose position is defined by $PS=90°-\delta$ and the hour angle $MPS=t$. The normal to the coelostat mirror at C lies in the plane of the equator and cuts the sphere at N. The first reflected ray has the direction CP', such that the angle of incidence $NS=i=NP'$. It follows at once that the polar distance of P' is $90°+\delta$. Its hour angle we will call t'. The direction CP' is also that of the center of the second mirror as seen from the center of the first, and may be defined by the co-ordinates A and z, the azimuth and zenith distance of the point P'.

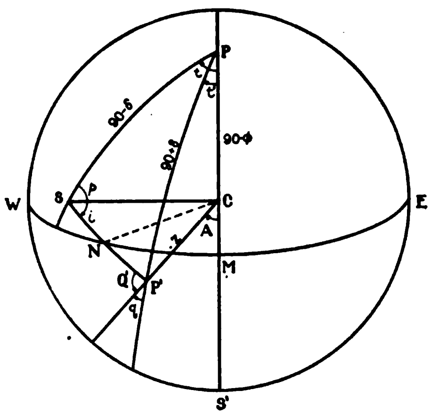


FIG. 2

The course of the beam of light is from S to C, then from C in the direction CP' until it strikes the second flat, whence it is reflected vertically downward through the objective of the telescope, reaching finally the polarizing apparatus and the spectrograph. The first incidence plane is therefore SCP'; the second, the vertical plane through C and P'. The angle between the two incidence planes is denoted by Q'. The first angle of incidence is i and the second $\frac{1}{2}z$.

We shall denote co-ordinates parallel to and perpendicular to

the first incidence plane (both perpendicular to the incident or the reflected ray, as the case may be) by p and n, respectively, and similar co-ordinates referred to the second incidence plane by p' and n'. The subscripts i and r will differentiate the incident and reflected rays. The convention governing the positive direction of p and n is as follows: Look along the incident (or reflected) ray in the direction of the reflecting surface with the normal directed upward. The positive direction of p will then be upward, and of n, to the left.

Figs. 3, 4, and 5 show the positive directions of the various sets of reference axes as seen from without the celestial sphere. The

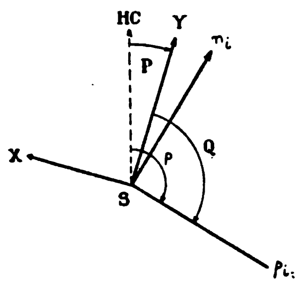


FIG. 3

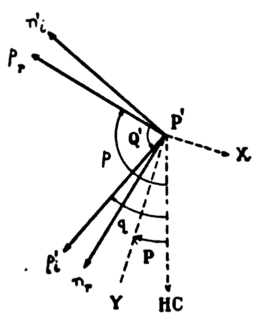


FIG. 4

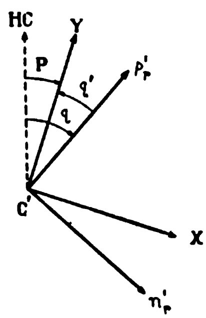


FIG. 5

general configuration is the same as Fig. 2, the north pole (actual, not reflected) in each instance lying above the figure in the direction of the hour circle HC. Fig. 3 gives the orientation in looking along the line SC in Fig. 2; Fig. 4, that seen in the direction $P'C$; and Fig. 5 that for the final direction of the beam (vertically downward) after reflection from the second flat whose center is at C' and situated on the line $P'C$. Thus p_i and p_r (Figs. 3, 4) lie in the plane SCP' and are respectively perpendicular to SC and $P'C$. Further, p'_i lies in the vertical plane through P' and C and is perpendicular to $P'C$. The direction of Y, the central solar meridian, is determined by the position angle of the sun's north point, P. From Fig. 3

$$Q=p-P. \tag{53}$$

The hour circle HC in Fig. 4 is the reflection of HC in Fig. 3. Since this coincides in direction with the actual hour circle $P'P$ (Fig. 2) through P', the relations between the angles p, q, Q' are as shown in Fig. 4, namely

$$Q'=p-q\,. \tag{54}$$

The final direction of the central meridian must be determined, as that fixes the position of the slit. It is indicated in Fig. 5 by $C'Y$. The orientation is given by

$$q'=q-P\,. \tag{55}$$

With these preliminary definitions established we may proceed to the detailed consideration of (52).

The determination of the resultant intensities parallel to and perpendicular to the slit involves the following steps: (a) a rotation of the reference axes XY through the angle Q, which gives the values of n_i and p_i; (b) an application of the reflection equations (50) and (51) giving n_r and p_r; (c) a rotation of the axes through the angle Q', which determines n'_i and p'_i; (d) a second application of the reflection equations resulting in n'_r and p'_r; (e) a rotation of the axes through the angle q', giving the co-ordinates x_i and y_i of the vibrations incident upon the quarter-wave plate, referred to directions respectively perpendicular to and parallel to the slit; (f) the introduction of the transformation produced by the quarter-wave plate, which determines the co-ordinates x' and y' of the vibrations falling upon the Nicol. The squares of the amplitudes of the resultant vibrations parallel to x' and y' are the required intensities. These steps will be considered in turn.

a) The typical elliptic vibration

$$x=a\sin\omega t\,,\quad y=b\cos\omega t \tag{56}$$

may be written

$$\left.\begin{aligned}x&=A\sin\omega t+B\sin\omega t\\ y&=A\cos\omega t-B\cos\omega t\end{aligned}\right\} \tag{57}$$

in which

$$A=\tfrac{1}{2}(a+b),\quad B=\tfrac{1}{2}(a-b)\,. \tag{58}$$

Equations (57) represent two superimposed circular vibrations, the first of which is negative (clockwise), the second positive. The rotation of the axes through the negative angle Q (Fig. 3) decreases

the phase of the first circular vibration, and increases that of the second, by Q. Consequently

$$\left.\begin{aligned} n_i&=A\sin(\omega t-Q)+B\sin(\omega t+Q)\\ p_i&=A\cos(\omega t-Q)-B\cos(\omega t+Q)\end{aligned}\right\}\tag{59}$$

b) The application of the reflection equations (50) and (51) requires the multiplication of the incident amplitudes A and B by the factor h, and the introduction of the relative phase change Δ in n and p. As a result of the former, we shall have h appearing as a common factor in all of the amplitudes. Since we are interested only in relative intensities, we may omit this factor and assume that the reflected amplitudes are directly A and B. The changes of phase in n and p are respectively δ_p and δ_n, with the condition

$$\delta_p-\delta_n=\Delta\,.$$

We shall suppose

$$\delta_p=\delta+\tfrac{1}{2}\Delta\,,\quad \delta_n=\delta-\tfrac{1}{2}\Delta\,.$$

Since the origin of phase is arbitrary, the common part δ may be dropped. The co-ordinates of the vibrations reflected from the first mirror are therefore

$$\left.\begin{aligned} n_r&=A\sin\left(\omega t-Q-\frac{\Delta}{2}\right)+B\sin\left(\omega t+Q-\frac{\Delta}{2}\right)\\ p_r&=A\cos\left(\omega t-Q+\frac{\Delta}{2}\right)-B\cos\left(\omega t+Q+\frac{\Delta}{2}\right)\end{aligned}\right\}\tag{60}$$

Expanding, (60) may be written

$$\left.\begin{aligned} n_r=A\cos\frac{\Delta}{2}\sin(\omega t-Q)-A\sin\frac{\Delta}{2}\cos(\omega t-Q)&+\\ B\cos\frac{\Delta}{2}\sin(\omega t+Q)-B\sin\frac{\Delta}{2}\cos(\omega t+Q)&\\ p_r=A\cos\frac{\Delta}{2}\cos(\omega t-Q)-A\sin\frac{\Delta}{2}\sin(\omega t-Q)&-\\ B\cos\frac{\Delta}{2}\cos(\omega t+Q)+B\sin\frac{\Delta}{2}\sin(\omega t+Q)&\end{aligned}\right\}\tag{61}$$

c) Equations (61) represent four superimposed circular vibrations whose amplitudes are $A\cos\frac{\Delta}{2}$, $A\sin\frac{\Delta}{2}$, $B\cos\frac{\Delta}{2}$, and $B\sin\frac{\Delta}{2}$. The first and fourth are negative, the second and third positive.

The rotation of the axes through the positive angle Q' (Fig. 4) for the purpose of obtaining the co-ordinates n'_i and p'_i perpendicular to and parallel to the second incidence plane decreases the phase of the positive circular vibrations, and increases that of the negative vibrations, by Q'. It will be observed from Fig. 4 that such a rotation will bring p_r into coincidence with p'_i, but that n_r will be opposite in direction to n'_i. Consequently the sign of the first co-ordinate must be changed. We have therefore from (61)

$$\begin{aligned} n'_i = & -A\cos\frac{\Delta}{2}\sin(\omega t-Q+Q')+A\sin\frac{\Delta}{2}\cos(\omega t-Q-Q') \\ & -B\cos\frac{\Delta}{2}\sin(\omega t+Q-Q')+B\sin\frac{\Delta}{2}\cos(\omega t+Q+Q') \\ p'_i = & +A\cos\frac{\Delta}{2}\cos(\omega t-Q+Q')-A\sin\frac{\Delta}{2}\sin(\omega t-Q-Q') \\ & -B\cos\frac{\Delta}{2}\cos(\omega t+Q-Q')+B\sin\frac{\Delta}{2}\sin(\omega t+Q+Q')\,. \end{aligned}$$

Expanding the sine and cosine factors and restoring the values of a and b by (58), it appears that these expressions may be written in the form

$$\left.\begin{aligned} n'_i &= A_n\sin\omega t+B_n\cos\omega t \\ p'_i &= A_p\sin\omega t+B_p\cos\omega t \end{aligned}\right\} \qquad (62)$$

in which

$$\left.\begin{aligned} A_n &= -a\cos\frac{\Delta}{2}\cos(Q-Q')+b\sin\frac{\Delta}{2}\sin(Q+Q') \\ B_n &= +b\cos\frac{\Delta}{2}\sin(Q-Q')+a\sin\frac{\Delta}{2}\cos(Q+Q') \\ A_p &= +a\cos\frac{\Delta}{2}\sin(Q-Q')-b\sin\frac{\Delta}{2}\cos(Q+Q') \\ B_p &= +b\cos\frac{\Delta}{2}\cos(Q-Q')+a\sin\frac{\Delta}{2}\sin(Q+Q') \end{aligned}\right\} \qquad (63)$$

d) The second application of the reflection equations is precisely similar to the first. Denoting the relative change of phase by Δ', we have from (62)

$$\left.\begin{aligned} n'_r &= A_n\sin\left(\omega t-\frac{\Delta'}{2}\right)+B_n\cos\left(\omega t-\frac{\Delta'}{2}\right) \\ p'_r &= A_p\sin\left(\omega t+\frac{\Delta'}{2}\right)+B_p\cos\left(\omega t+\frac{\Delta'}{2}\right) \end{aligned}\right\} \qquad (64)$$

These may be written

$$\left.\begin{aligned} n'_r &= A'_n \sin \omega t + B'_n \cos \omega t \\ p'_r &= A'_p \sin \omega t + B'_p \cos \omega t \end{aligned}\right\} \tag{65}$$

in which

$$\left.\begin{aligned} A'_n &= A_n \cos \frac{\Delta'}{2} + B_n \sin \frac{\Delta'}{2}\,, \quad B'_n = -A_n \sin \frac{\Delta'}{2} + B_n \cos \frac{\Delta'}{2} \\ A'_p &= A_p \cos \frac{\Delta'}{2} - B_p \sin \frac{\Delta'}{2}\,, \quad B'_p = +A_p \sin \frac{\Delta'}{2} + B_p \cos \frac{\Delta'}{2} \end{aligned}\right\} \tag{66}$$

e) The values of the co-ordinates perpendicular to and parallel to the slit are connected (Fig. 5) with n'_r and p'_r by

$$\begin{aligned} x_i &= n'_r \cos q' + p'_r \sin q' \\ y_i &= -n'_r \sin q' + p'_r \cos q'\,. \end{aligned}$$

Substituting from (65), we find

$$\left.\begin{aligned} x_i &= \alpha \sin \omega t + \beta \cos \omega t \\ y_i &= \gamma \sin \omega t + \delta \cos \omega t \end{aligned}\right\} \tag{67}$$

in which

$$\left.\begin{aligned} \alpha &= +A'_n \cos q' + A'_p \sin q'\,, \quad \beta = +B'_n \cos q' + B'_p \sin q' \\ \gamma &= -A'_n \sin q' + A'_p \cos q'\,, \quad \delta = -B'_n \sin q' + B'_p \cos q' \end{aligned}\right\} \tag{68}$$

f) To introduce the transformation effected by the quarter-wave plate we require the components of (67) in the direction of the principal axes of the mica strips composing the plate. For two adjacent strips these are inclined to the axes of x_i and y_i at angles of $+45°$ and $-45°$. We need consider but the first, for which

$$\left.\begin{aligned} \xi &= \frac{1}{\sqrt{2}}(+x_i + y_i) = \frac{1}{\sqrt{2}}(\gamma + \alpha) \sin \omega t + \frac{1}{\sqrt{2}}(\delta + \beta) \cos \omega t \\ \eta &= \frac{1}{\sqrt{2}}(-x_i + y_i) = \frac{1}{\sqrt{2}}(\gamma - \alpha) \sin \omega t + \frac{1}{\sqrt{2}}(\delta - \beta) \cos \omega t \end{aligned}\right\} \tag{69}$$

Assuming that the "fast" direction of the mica strip considered coincides with ξ, and denoting the emergent values of ξ and η by ξ' and η', we have

$$\left.\begin{aligned} \xi' &= \frac{1}{\sqrt{2}}(\gamma + \alpha) \cos \omega t - \frac{1}{\sqrt{2}}(\delta + \beta) \sin \omega t \\ \eta' &= \frac{1}{\sqrt{2}}(\gamma - \alpha) \sin \omega t + \frac{1}{\sqrt{2}}(\delta - \beta) \cos \omega t \end{aligned}\right\} \tag{70}$$

in which the common part of the phase change in ξ and η is neglected. The components of (70) perpendicular to and parallel to the slit are given by

$$\left.\begin{aligned} x'&=\frac{1}{\sqrt{2}}(\xi'-\eta')=\alpha'\sin\omega t+\beta'\cos\omega t\\ y'&=\frac{1}{\sqrt{2}}(\xi'+\eta')=\gamma'\sin\omega t+\delta'\cos\omega t \end{aligned}\right\} \tag{71}$$

in which

$$\left.\begin{aligned} \alpha'&=\tfrac{1}{2}(+\alpha-\beta-\gamma-\delta),\quad \beta'=\tfrac{1}{2}(\alpha+\beta+\gamma-\delta)\\ \gamma'&=\tfrac{1}{2}(-\alpha-\beta+\gamma-\delta),\quad \delta'=\tfrac{1}{2}(\alpha-\beta+\gamma+\delta) \end{aligned}\right\} \tag{72}$$

Since the two terms in the right members of (71) differ in phase by 90°, the intensities of the vibrations incident upon the Nicol parallel to x' and y' are respectively

$$I_x=\alpha'^2+\beta'^2,\quad I_y=\gamma'^2+\delta'^2.$$

For an adjacent strip of the quarter-wave plate the results will be the same, but with an interchange of the values of I_x and I_y. As the Nicol transmits only those vibrations which are parallel to the slit, we have for the intensity of the light entering the spectrograph from the two strips

$$I=\alpha'^2+\beta'^2,\quad I'=\gamma'^2+\delta'^2. \tag{73}$$

The expression of I and I' in terms of the original amplitude a, the phase retardations Δ and Δ', and the various angles involved is accomplished by successive substitution back through (73), (72), (68), (66), and (63). The operations involved are tedious, but not difficult. Only the results of the successive steps need be given here. From (73) and (72) we obtain

$$\left.\begin{aligned} I&=\tfrac{1}{2}(\alpha^2+\beta^2+\gamma^2+\delta^2)-\alpha\delta+\beta\gamma\\ I'&=\tfrac{1}{2}(\alpha^2+\beta^2+\gamma^2+\delta^2)+\alpha\delta-\beta\gamma \end{aligned}\right\} \tag{74}$$

By (68), (66), and (63),

$$\begin{aligned} \alpha^2+\beta^2+\gamma^2+\delta^2&=A_n'^2+A_p'^2+B_n'^2+B_p'^2\\ &=A_n^2+A_p^2+B_n^2+B_p^2\\ &=a^2+b^2. \end{aligned} \tag{75}$$

Again, by (68) and (66),

$$\begin{aligned} -\alpha\delta+\beta\gamma&=A_p'B_n'-A_n'B_p'\\ &=-(A_nA_p+B_nB_p)\sin\Delta'+(A_pB_n-A_nB_p)\cos\Delta'. \end{aligned} \tag{76}$$

Further, by (63),

$$A_nA_p+B_nB_p=\tfrac{1}{2}(a^2-b^2)(\cos 2Q \sin 2Q'-\sin 2Q \cos 2Q' \cos \Delta)+ ab \cos 2Q' \sin \Delta . \tag{77}$$

$$A_pB_n-A_nB_p=\tfrac{1}{2}(a^2-b^2) \sin 2Q \sin \Delta+ab \cos \Delta . \tag{78}$$

Substituting (77) and (78) into (76), and the result, together with (75), into (74) gives

$$\left.\begin{aligned} I &=\tfrac{1}{2}(a^2+b^2)+\lambda+\mu \\ I' &=\tfrac{1}{2}(a^2+b^2)-\lambda-\mu \end{aligned}\right\} \tag{79}$$

in which λ and μ have the values

$$\left.\begin{aligned} &\lambda=ab(\cos \Delta \cos \Delta'-\sin \Delta \sin \Delta' \cos 2Q') \\ &\mu=\tfrac{1}{2}(a^2-b^2)\{\sin 2Q \sin \Delta \cos \Delta'- \\ &\quad (\cos 2Q \sin 2Q'-\sin 2Q \cos 2Q' \cos \Delta) \sin \Delta'\} \end{aligned}\right\} \tag{80}$$

The original elliptic vibration (56) whose intensities are given by (79) has the form of the first of (52). Let us assume that this represents the red component of the triplet line observed. The intensities of the violet component may be found by changing the sign of b in (79) and (80). Further, the intensities for the middle component may be derived by writing $a=0$, $b=\sqrt{2}\, a \sin \gamma$. Since for the red and violet components, b in (80) has the value $a \cos \gamma$, we have

$$\begin{aligned} \lambda_V &= -\lambda_R , \quad \mu_V = \mu_R \\ \lambda_M &= \quad 0, \quad \mu_M = -2\mu_R = -2\mu_V \end{aligned}$$

in which the subscripts designate the components to which the values of λ and μ refer. Denoting now the intensities of the three components in one of two adjacent spectrum strips by V, M, and R, we have from (79)

$$\left.\begin{aligned} V &=\tfrac{1}{2}a^2(1+\cos^2\gamma)-\lambda+\mu \\ M &=a^2\sin^2\gamma \qquad\quad -2\mu \\ R &=\tfrac{1}{2}a^2(1+\cos^2\gamma)+\lambda+\mu \end{aligned}\right\} \tag{81}$$

The intensities V', M', R', for the second spectrum strip are the same as (81) except that the signs of λ and μ are reversed.

Equations (81) correspond to (10) of the first part of the development. For the determination of the displacement of the resultant

of the three components we proceed as in the case of equations (12)-(18). Since (81), by,

$$R-V=2\lambda\,,\quad V+M+R=2a^2\,.$$

we have finally

$$\Delta=2\,\sigma\epsilon\cos\gamma, \tag{82}$$

in which the factor ϵ has the value

$$\epsilon=\cos\Delta_1\cos\Delta_2-\sin\Delta_1\sin\Delta_2\cos 2Q'\,. \tag{83}$$

The symbols Δ and Δ' previously used for the relative phase retardations at the reflecting surfaces are here replaced by Δ_1 and Δ_2 to avoid a possible confusion with the displacement Δ in (82). If (82) be compared with (18), it will be seen that the effect of the elliptical polarization produced by the two reflections from the coelostat mirrors is only to introduce the factor ϵ defined by (83). Q', it will be recalled, is the angle included between the two incidence planes.

The angles Δ_1, Δ_2, and Q' are all functions of t and δ, the hour angle and declination of the sun. Although ϵ is not readily expressed explicitly in terms of these quantities, its values are easily calculated for any given t and δ. To obtain an idea of the magnitude of the polarization effect, it will be convenient to tabulate ϵ with t and δ as arguments.

For the calculation of the phase retardations, the angles of incidence are required, and for Q' the angles p and q. From $\triangle\,SPN$, Fig. 2 we find

$$\tan p=-\tan\tau\operatorname{cosec}\delta\,,\quad \sin i=\sin\tau\operatorname{cosec}p, \tag{84}$$

in which

$$\tau=\tfrac{1}{2}(t-t')\,.$$

Further from $\triangle\,PCP'$,

$$\sin q\sin z=\cos\phi\sin t'\,. \tag{85}$$

The angle of incidence for the second mirror is $i'=\frac{1}{2}z$. These relations may be used for the calculations of i, i', and $Q'=p-q$, whence Δ_1 and Δ_2 may be derived by (51). There remains still, however, the expression of z and t' as functions of δ. These quantities are the zenith distance and hour angle of the center of the second mirror as seen from the center of the first, and are independent of t.

The elevation of the second flat above the first is 915 mm. For morning observations the coelostat is set 600 mm east of the second mirror, while during the afternoon it is 600 mm west. This increases the average angle of incidence for the first mirror, but permits a continuation of observations past the meridian without interference from the shadow of the second flat.

If d represent the projection upon a horizontal plane of the line joining the centers of the two mirrors, and if A and z be the azimuth and zenith distance of the second referred to the first, then

$$\sin A = \frac{600}{d}, \quad \tan z = \frac{d}{915},$$

whence

$$\sin A \tan z = \frac{600}{915}. \tag{86}$$

Now from $\triangle$ PCP', Fig. 2

$$\sin A \sin z = \cos \delta \sin t',$$

and by (86)

$$\cos z = 1.525 \cos \delta \sin t'. \tag{87}$$

Again, from the same triangle

$$\cos z = -\sin \delta \sin \phi + \cos \delta \cos \phi \cos t'. \tag{88}$$

It is to be noted that for the conditions here assumed, the values of t' and q are negative. The last two equations serve for the determination of z and t' in terms of δ. The solution is therefore complete, the necessary formulae for the derivation of ϵ being (87) and (88), which are readily solved by approximations, and (85), (84), (54), (51), and (83).

Their application gives the following results:

VALUES OF THE POLARIZATION FACTOR ϵ

δ	t						
	0^h	1^h	2^h	3^h	4^h	5^h	6^h
$+25°$..........	0.96	0.95	0.94	0.93	0.91	0.86	0.78
$+15$..........	0.98	0.98	0.97	0.96	0.94	0.88	0.78
$+5$..........	0.99	0.99	0.99	0.97	0.95	0.88	0.77
-5..........	1.00	1.00	0.99	0.97	0.93	0.86	0.72
-15..........	1.00	0.99	0.98	0.95	0.90	0.81	0.63
-25..........	0.99	0.98	0.96	0.92	0.84	0.72	0.51

The values for the optical constants used in (51) are for normal silver and relate to sodium light, which agrees closely in wave-length with the lines observed by Mr. Hale. It cannot be supposed, however, that the values used will apply accurately to the mirrors, even when freshly silvered and burnished. Drude has found,[1] for example, that but few metals remain uncontaminated when polished with rouge, and the account of his experiments seems to imply that this is the case with silver. Generally speaking, variations in the constants may be produced by the presence of a superficial film of some foreign substance, and by minute scratches or furrows in the surface of the metal. Although the results for silver are extremely sensitive to the latter, it is probable that with a carefully burnished mirror we may disregard this source of disturbance. As for the former, Drude has shown[2] that the presence of a superficial film is invariably to reduce the principal angle of incidence, and also the value of Δ corresponding to any given incidence, the amount depending upon the thickness and the index of refraction of the film. The principal azimuth, on the other hand is slightly increased.

These modifications affect the above results in two directions: first, through the approximations used for ρ' and Q, whose true values are defined by (45) and (48), and second, by a direct change in ϵ. Since

$$\kappa = \tan Q = \tan 2\bar{\psi}, \qquad (2\bar{\psi} < 90^\circ)$$

in which $\bar{\psi}$ is the principal azimuth,[3] it follows that the minimum value of ρ' (p. 15) is increased by the presence of the superficial film, and that the approximation for Q is likewise improved. The effect upon ϵ, however, is less favorable. The form of (51) assumes that for values of i less than the principal incidence, which corresponds to the conditions of observation, $180^\circ > \Delta > 90^\circ$. A decrease in Δ therefore means a decrease in ϵ; but beyond this general statement it is impossible to specify without definite knowledge of the properties of the film. Broadly speaking, however, it may be said that, with ordinary care in the treatment of the mirrors, it is very improbable that any serious modification

[1] *Annalen der Physik*, **39**, 503, 1890. [2] *Ibid.*, p. 488.

[3] Drude, "Theory of Optics," translated by Mann and Millikan, p. 364, 1902.

of the results will occur, provided that the observations be restricted to moderate values of the hour angle.

The preceding results are in part a continuation of an investigation begun by Mr. J. A. Anderson, who first derived by a somewhat different method equations (10) for the intensities of the three components in any spectrum strip. These were numerically applied by him to a special case, in which it was assumed that the observer is in the plane of the sun's equator and that the magnetic axis coincides with the solar axis of rotation. The resulting displacement-curve was apparently a sine curve. The extension of the theory here given was rendered desirable for the discussion of the observational data relating to the sun's general magnetic field secured by Mr. Hale. I am further indebted to Mr. Anderson for a careful examination and control of the numerous transformations involved in the development of the polarization factor.

SUMMARY

The preceding discussion is concerned with two questions: (*a*) the development of the theoretical curve of displacements produced in the spectrum by the sun's general magnetic field, when observed with the spectrograph and polarizing apparatus of the 150-foot tower telescope; (*b*) the effect upon this curve of the elliptical polarization introduced by the reflections from the silvered surfaces of the coelostat mirrors.

For a normal Zeeman triplet the theoretical displacement curve, equation (31), is a function of the heliographic latitude, the position of the observer, and the solar magnetic elements. It is a sine curve differing but little from $k\Delta = 3 \sin 2\phi$, and has therefore, zero values near the equator and the poles, and maxima (absolute) near 45° N. and S. It is readily adapted to the calculation of the solar magnetic elements.

The effect of the elliptical polarization produced by the tower mirrors is to introduce a factor ϵ, equation (83), which, for normal observing conditions, flattens by a negligible amount the curve of displacements.

MOUNT WILSON SOLAR OBSERVATORY
April 17, 1913

REVIEWS

Handbuch der Spectroscopie. Von H. KAYSER, Professor der Physik an der Universität Bonn. Leipzig: Hirzel, 1912. Band VI. Pp. vi+1067.

The stupendous undertaking upon which Professor Kayser entered more than a quarter of a century ago was the production of a historical compendium which should contain practically all that is known concerning the subject of spectroscopy. The completion of such a work is a noteworthy event in the annals of this science.

The preface of the last volume contains a brief review of the entire project and describes certain changes of plan, all of which is so frank and so full of personal interest that the first three paragraphs are here translated:

When I was writing the preface to the first volume of this work in 1900, I thought the purely physical part of spectroscopy could be treated in four volumes; and I had in mind a fifth volume devoted to spectroscopy as applied in astrophysics. I had hoped to complete the task within ten or twelve years. Already, however, twelve strenuous years have passed and only that portion devoted to physics has been finished. The four volumes originally designed have grown to six. During these twelve years the literature to be worked up has enormously increased; and I may perhaps be allowed to assume that some of this growth in spectroscopic investigation is owing to my work. At that time I stated that I had read and excerpted 7000 spectroscopic papers; but, in the meantime, this number has been doubled. Hence the increase in size and the consequent delay of this work.

As I glance over the astrophysical literature of today it is clearly evident that the single volume which I had intended for this purpose would be quite inadequate; no less than three volumes would suffice, and I should have to devote to it not less than eight years. Nor can I fail to realize that, in the meantime, I have advanced too far in years to undertake such a new work; my university duties have grown, my free time has diminished, my ability to work has waned, and, most important of all, my memory is not to be trusted as formerly: failing which such a work cannot be written. It is not, therefore, without some degree of sadness that I have arrived at the decision to leave these astrophysical applications, in which I have been especially interested, to younger hands, hoping that the proper man will shortly be discovered.

If, in a certain sense, this volume marks the close of my life-work—I took up the subject of spectroscopy in 1880 and since 1887 have devoted to it

almost my entire time—I am nevertheless hoping to pursue these questions still farther. Our scientific output has become so enormous as to render a work of this kind out of date even at the moment of its publication. Time and again I have had to ask the printer to return my manuscript in order that I might include in it some new result which had just appeared and which deserved consideration. In other cases this was impossible. For this reason the volumes published ten years ago are already somewhat antiquated and in need of revision; this I am still hoping to carry out.

Passing now to the text of the volume, this includes the discussion of all elements whose symbols fall within the last half of the alphabet. The first of these is sodium, to which are devoted 127 pages. The treatment of this element—like those of *Rb*, *S*, *Se*, and *Te*—is by Professor Konen of Münster; the number of original papers cited is 678. The behavior of this element is viewed from so many standpoints, such as that of temperature, magnetic field, reversals, character of source, series, fluorescence, dispersive media, etc.; and its history is so completely given, that these 127 pages, by themselves, almost constitute a modern treatise on spectroscopy.

No rigid plan is adopted for the discussion of each element; but the usual procedure is something like the following: the literature of the element is listed in chronological order; next follows the history, general behavior, and peculiarities of the element; this is followed by a description of the line spectrum including tables of wave-lengths as observed in arc and spark; after this, the banded spectra and spectra of compounds. Under these various headings are frequent subdivisions: e.g., five different banded spectra for strontium, eight different types of line spectra for sodium. Nearly all the wave-lengths are necessarily given in terms of Rowland's standards; a few based on the International Unit have appeared in time to be included; such are Kilby's values for titanium, Bachem's for zirconium, and Burns's for iron.

The last two hundred pages, approximately, are devoted to three tables which are certain to be of the utmost value to every spectroscopist who is concerned with either the identification of lines or the determination of wave-lengths.

The first of these tables is a list of iron lines including both secondary and tertiary standards ranging from λ 8863 to λ 2212, distributed at intervals which average about 1½ Å. Intensities are given for both arc and spark. The manner in which the values here tabulated have been obtained may be briefly described by saying that the author has used his best judgment in taking a weighted mean of all the best measures

available. In general the accuracy is estimated at 1 or 2 hundredths of an Ångström unit, and the second decimal is given; the values of the interferometer measures are given to the third decimal, since here the errors are supposed to be less than one-hundredth of an Ångström; some hazy lines are listed only to the first decimal. All lines except a few at the red end have their wave-lengths given both in the International and in the Rowland system. The second table is a list of the "Chief Lines in the Linear Spectra" of the elements, arranged in order of wave-length. Here again wave-lengths are given to the second decimal in both the International and Rowland systems; arc and spark lines are each included on the ground that any distinction between them is artificial—*schädlich und wiedersinnig*. In the last three columns are given the various intensities of each line in the arc, spark, and vacuum tube. One will rarely meet any impurity line not given in this table, and he cannot therefore help wishing that it might, for the sake of convenience, be reprinted as a a separate volume. Here is included the most recent work of Eder and Valenta as well as many yet unpublished measures from the author's own laboratory. The attempt has been to include all lines of intensity of 4 or greater, on a scale of increasing strength running from 1 to 10; but this rule has not been followed in a slavish way. The third and last table includes the wave-lengths of some 3000 edges of banded spectra, giving in addition the source and the direction in which the band shades off, whether toward the red or the violet.

If it were not already true that an easy reading knowledge of German is an absolute necessity for any serious student of spectroscopy, the completion of this handbook would certainly make it true; for this work is the one indispensable treatment of its subject. Professor Kayser surely deserves, and as surely has, the congratulations and the thanks of his fellow-workers and fellow-students in all parts of the world.

HENRY CREW

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ON THE INTERPRETATION OF PHOTOSPHERIC PHENOMENA

By W. H. JULIUS

It is a common belief that a body always presenting the appearance of a circular disk, from whichever side it is looked at, must be bounded by a spherical surface. The general conviction that the bulk of the sun is an incandescent sphere rests on that belief, and was a natural starting-point for solar theories.

After the effective solar temperature had been found so high as to exceed the critical temperatures of perhaps all known substances, the earlier idea that the main body of the sun was in the liquid or the solid state had to be replaced by the hypothesis that it is substantially gaseous. This new idea involved the necessity of explaining the phenomenon of the apparent "solar surface." One had to choose between Young's view, that the photosphere was a layer of incandescent clouds produced by condensation of certain substances having exceptionally high critical temperatures, and Secchi's hypothesis (afterward developed by Schwarzschild and Emden), which dispenses with assuming cloud-formation by supposing the density of the solar gases to increase so rapidly with depth near the level called "solar surface," that within a layer no more than a thousand kilometers thick, their united radiating power increases from a very low value (in the chromosphere) up to that of the black body (in the photosphere).

In 1891 August Schmidt took a new departure when showing that an entirely gaseous body of the dimensions of the sun, in which the density and the radiating power gradually decrease from the center outward, be it even at a slow rate, must appear like a circular luminous disk with a sharp edge, as a mere consequence of ray-curving caused by the radial density gradient. So the circular aspect of the sun is *not* a sufficient ground for admitting the existence of a real "photosphere," that is, of a layer characterized by some abrupt, or even only rapid, change of physical properties.

Schmidt's well-known solar theory, however, met with the severe objection that it did not duly consider the effect of absorption and scattering of the light.[1] Rays having accomplished such long distances on their spiral paths inside the critical sphere would be almost wholly extinguished before emerging; they could not possibly bring along so much energy from the incandescent core as would be required in order to account for the brilliancy observed in the marginal parts of the disk. In its original form the optical interpretation of the sun's edge cannot be maintained.

It is also impossible to accept the cloud-theory of the photosphere, because the results of the radiation-measurements made at Maastricht during the annular eclipse of 1912[2] forbid making an absorbing or scattering solar atmosphere responsible for the fall of the sun's brightness from the center toward the limb. Indeed, the absorbing and scattering power of the gases lying outside the photosphere proved to be relatively insignificant. The photosphere, therefore, cannot be of such a nature that it would appear like a uniformly luminous disk if the surrounding gases were absent. On the contrary, it must have in itself the property of appearing much brighter when looked at in the direction of a radius than at an angle with the radius; and the law of variation of brightness with the angle is different for different wave-lengths.

Whatever the causes may be that make the sun radiate more intensely in the direction of the radius than in directions slanting to it, they must be looked for in layers lying *below* the level generally called the surface of the photosphere. Those layers consist of

[1] R. Emden, *Gaskugeln*, pp. 388–394; Pringsheim, *Physik der Sonne*, pp. 266–270.

[2] *Astrophysical Journal*, **37**, 225, 1913.

transparent gases, for the slightest haze of condensation products, occupying a stratum some thousand kilometers thick, would provide it with a radiating and scattering power almost independent of direction, which power the photosphere does not possess.

Assuming, on the basis of the Maastricht results, that the extinction effected by the sun's outer layers is comparatively small, we derive, from direct observations on the distribution of brightness on the sun's disk (Vogel, Abbott), how much light of a given wave-length a point *M*, lying somewhere in the photospheric level, transmits on the average along the various directions. The result

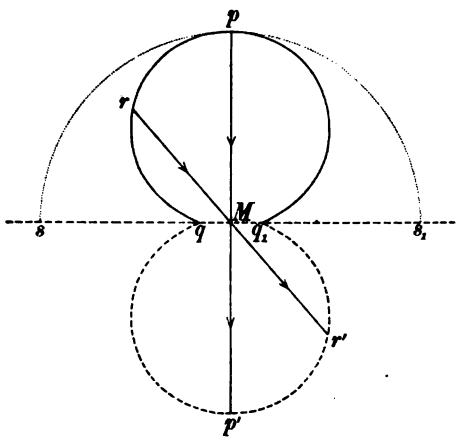

FIG. 1

may conveniently be described, for every wave-length separately, by means of an "irradiation surface" qpq_1 (Fig. 1),[1] the radii vectores of which represent the average intensities of the light reaching *M* from different sides. We obtain the "radiation or emission surface" $qp'q_1$ of *M* by prolonging the radii *rM* and making $Mr'=rM$.

If we wish to explain the sun's apparent, fairly sharp, boundary, and the law of varying brightness of the solar disk, we shall have to consider, besides emission and absorption, the effects of dispersion, refraction, and molecular scattering of the light traversing an

[1] For a method of constructing these surfaces we refer to *Physik. Zeitschr.*, **12**, 677, 1911; or, *Handwörterbuch der Naturwissenschaften*, VII, 830.

entirely gaseous medium. This is a great physical problem, toward the complete solution of which only the first steps are being made as yet;[1] but awaiting the final results of such investigations, we may already inquire into their possible bearing on solar problems.

From the astrophysical point of view one of the questions material to the case is: What can be presumed about the general radial gradient of the density in the layers we are concerned with?

This subject has been treated very fully and ingeniously, on the basis of thermodynamics, by Emden in his book *Gaskugeln*. Emden arrives at the conclusion already mentioned above, that the fall of the density must be extremely rapid; but the inference is open to doubt, for in his calculations Emden presupposes gravitation to be the only radial force acting on solar matter. According to the present state of our physical knowledge, however, we decidedly must admit that on the sun gravitation is counteracted by the pressure of radiation, and by the emission of electrons and perhaps of other charged particles.

Basing on purely theoretical grounds an estimate of the intensity of that counteraction would, for the present, be as rash as denying its existence; but some evidence in favor of its essentiality is given by the fact that many solar phenomena are much better understood if we assume a radial gradient many times smaller than the one that would correspond to gravitational conditions only. In this connection we call attention to the puzzling properties of quiescent, hovering prominences. Father Fényi, in his interesting discussion of the long series of prominence observations made at Haynald Observatory, Kalocsa,[2] is very positive in his assertion that several well-established facts concerning quiet prominences can be accounted for only if in the solar atmosphere gravity is reduced, by certain repulsive forces, to a small fraction (something of the order 1/80) of its commonly accepted value.

[1] Rayleigh, *Phil. Mag.* (5), **47**, 375, 1899; A. Schuster, *Astrophysical Journal*, **21**, 1, 1905; H. A. Lorentz, *The Theory of Electrons*, Leipzig, 1909; L. Natanson, *Bulletin de l'académie des science de Cracovie*, Avril 1907, Décembre 1909; W. H. Julius, *Physik. Zeitschr.*, **12**, 329 and 674, 1911; L. V. King, *Phil. Trans. Roy. Soc. London*, **212** A, 375, 1912.

[2] *Publikationen des Haynald Observatoriums*, Heft X, 138, 1911; cf. also Fényi, "Ueber die Höhe der Sonnenatmosphäre," *Mem. Spettr. ital.* (2), **1**, 21, 1912.

Our hypothesis, that a similar counteraction, opposing the effect of gravitation, prevails throughout the visible layers of the sun, is certainly not less plausible, therefore, than the exclusive hypothesis, usually admitted, which makes gravitation the only effective agent in determining the radial gradient.[1]

We must now endeavor to conceive the appearance of the sun's edge in a transparent gaseous medium where the pressure varies but slowly along the radius.

As already remarked, Schmidt's ingenious optical explanation cannot be adhered to. Nevertheless the principle of ray-curving introduced by that author is extremely suggestive; it leads to the following interpretation of the solar limb, that appears not to encounter similar difficulties.

Let Fig. 2 represent an equatorial section of the sun. It can hardly be doubted that besides the gradual, perhaps slow variation of optical density corresponding to the outward decrease of pressure, there are many *irregular optical density-gradients* connected not only with the local differences of pressure that accompany the convection currents and solar vortices, but also with the differences of temperature and of composition occurring in the gaseous mixture.

Now, the average magnitude of those irregular gradients of optical density will very probably decrease as we proceed from a level P toward a level Q.

Let us imagine the "irradiation surfaces" to be constructed for a point P_1 of the level P and for a point Q_1 of Q. At the level Q the irregular gradients may in general be so small that rays, leaving it along a tangent Q_1E in the direction of the earth, are almost

[1] In this *Journal* (31, 166, 1910), Mr. J. A. Anderson has criticized the conclusions arrived at in my paper "Regular Consequences of Irregular Refraction in the Sun" (*Proc. Roy. Acad. Amst.*, October 28, 1909). His refutation of the idea that refraction might be very momentous in solar physics is entirely founded on the following two assumptions: (1) the photosphere may be represented by a perfectly uniform self-luminous surface, radiating approximately according to the cosine law, and (2) on the sun the weight of a gas is 27.3 times as great as on the earth. I think we may now safely state that the first assumption is contrary to observed facts, and that the second assumption is an unproved dogma, subject to well-founded doubts.

Moreover, a very important point, overlooked by Mr. Anderson, is that considerable optical density-gradients may result from differences of temperature or of composition, even at uniform pressure.

never sufficiently curved to be the continuation of rays coming from within the irradiation surface of Q_1. This condition will obtain if the average radius of curvature of rays tangent to the level Q is more than, say, three times as great as the radius of the sphere Q. Then the observer receives little light from Q_1; he will consider the level Q to lie outside the solar limb.

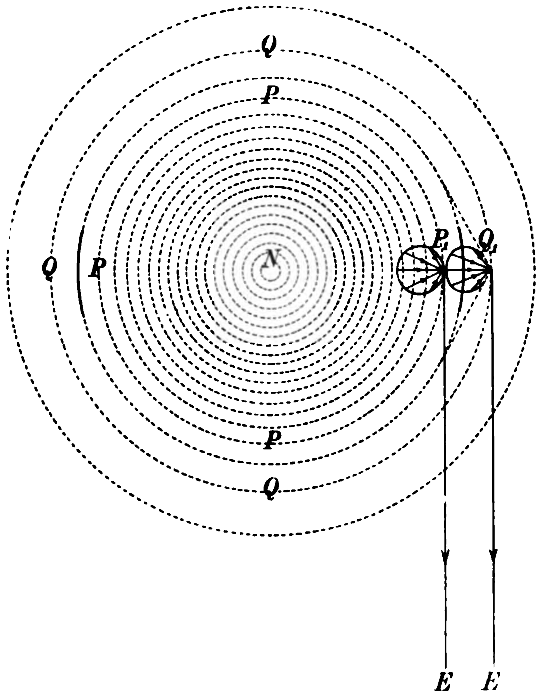

FIG. 2

If, on the other hand, in a layer P the gradients are so much steeper that there the average radius of curvature of tangential rays is smaller than, say, one-third of the radius of the sphere P, we may expect a sensible fraction of the light that P_1 receives from the interior to get sufficiently deviated in the region surrounding P_1, so as to proceed toward the earth along the tangent P_1E. The observer will now consider P_1 to belong to the solar disk.

The transition from disk to surroundings will appear abrupt if the minimum distance between levels like P and levels like Q be

less than 700 kilometers (one second of arc). This condition is compatible with a rather slow radial pressure gradient, because it only requires that the average radius of curvature[1] $(\rho=n\div\frac{dn}{ds})$ of rays deviated by irregular gradients of optical density be about 9 times greater in Q than in P. (Even a smaller ratio would probably suffice.) There will then appear a circular boundary between P and Q, lying in a plane through the sun's center perpendicular to the line of sight, but there is no particular "solar surface" corresponding to it.[2]

In a level P just inside the apparent photosphere the average value of ρ may still be of the order of magnitude 10^{10} cm. We can easily show that to such curvatures of rays quite reasonable density gradients correspond. For if we suppose hydrogen to be a principal constituent of the visible layers, the average refraction-constant $R=n-1/\Delta$ of the medium may be estimated at 1.5. Putting this value, and $\rho=10^{10}$, into the relation

$$\frac{d\Delta}{ds}=\frac{1}{R\rho}\,*$$

*Cf. *Astrophysical Journal*, 25, 107, 1907.

we obtain the density-gradient 6×10^{-11}, which means that in two points one kilometer (10^5 cm) distant from each other the density

[1] "Average radius of curvature" is here used as an abbreviated expression for "the radius of curvature corresponding to the average value of that radial component of the irregular density gradients, which is directed toward the center of the sun."

[2] At first sight one might be inclined to think that the boundary thus defined has the same radius as Schmidt's critical sphere would have. On closer examination, however, the two notions appear to be entirely different. This is clearly brought out with the aid of the following analogous conception. Imagine a spherical mass of liquid (radius R) of constant *average* optical density, and, as a source of light in the middle of it, an incandescent lamp provided with a big globe of milky glass (radius $\frac{1}{2}$ R). As there is no radial density-gradient, a critical sphere in the sense of Schmidt's theory could not appear in that medium. Let the liquid be a mixture of a solution of common salt and a solution of glycerine in water, both solutions having the same specific weight but different refracting power (cf. *Physik. Zeitschr.* 11, 59, 1910). If we now suppose that only in the outer spherical shell (radii R and $\frac{3}{4}$ R) the solutions are completely mixed, whereas in the inner shell surrounding the luminous globe the liquids are only stirred, but still honeycombed with irregular gradients of optical density—the *average* optical density of the shells being the same—then the inner shell will seem to be a self-luminous body. The origin of its boundary is comparable with that of the solar limb according to our theory.

The above interpretation of the photosphere evidently involves an explanation of the reversing layer and the chromosphere as soon as we take account of anomalous dispersion. On this subject, however, we shall not expatiate in the present paper.

only differs 0.000006, i.e., 0.5 per cent of the density of our terrestrial atmosphere. It would be very remarkable, indeed, if the general circulation in the sun did not bring along local differences of temperature and of composition sufficient to account for density-gradients of that order of magnitude. In a layer, for instance, where the average density does not exceed the density of our own atmosphere at sea-level, a temperature gradient of 1°4 C. per kilometer is all that would be required.

The above dioptrical conception of the photosphere implies the following explanation of the variation of brightness across the disk.

This problem, indeed, may also be expressed as follows: What is the cause of the fact that the *irradiation surface* of a point *M*,

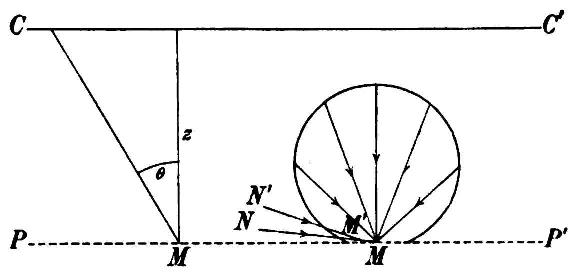

FIG. 3

lying somewhere in or near the "photospheric level," has that particular shape (different according to the selected wave-length) which direct observation assigns to it?

Let PP' (Fig. 3) represent a part of the photospheric level, CC' of another level lying so much deeper that there the solar matter is dense enough to emit light giving a continuous spectrum.

Although the medium surrounding M be a mixture of selectively absorbing gases, transparent to the greater part of the spectrum, that transparency is not absolute. *Molecular scattering* (Rayleigh)[1] weakens a *direct* beam according to the law $I=I_0e^{-sz}$, in which $s=\dfrac{32\pi^3(n-1)^2}{3\lambda^4N}$; but if the source of light be an incandescent surface CC' radiating the energy I_0 per square unit, and

[1] Rayleigh., *Phil. Mag.* (5), **47**, 375, 1899.

if the diffused light itself be taken into consideration, the energy emerging per square unit from PP' will (as found by Schuster[1]) be expressed thus:

$$I = I_0 \frac{2}{2+sz}.$$

We are aware that this formula does not hold exactly for non-homogeneous media, nor for oblique directions when simply replacing z by $z \sec \theta$; but as a first approximation we shall put

$$J = J_0 \frac{2}{2+s\,z \sec \theta},$$

where J and J_0 now refer to units of surface located in the layers PP' and CC' respectively, and taken perpendicular to the direction considered. Supposing J_0 to be independent of direction, we find that J decreases as θ increases, in agreement with the characteristic of the irradiation surface.[2]

One of the reasons why the latter equation cannot be expected to represent the conditions completely is that it does not allow for possible incurvation of the direct beams passing through the medium. If θ approaches the value 90°, our formula makes J tend toward zero, whereas in reality the brightness at the limb only falls to values between 0.13 $J_{\theta=0}$ and 0.30 $J_{\theta=0}$ with different colors. Now, it is evident that refraction by the irregular density-gradients at once accounts for the discrepancy; indeed, a beam reaching M along NM (θ nearly=90°) might have been turned into that direction from another direction $N'M'$ for which θ has a smaller value, so that J will have a greater value than the one corresponding to the formula. It is exactly this process on which our explanation of the sun's edge was based.

[1] Schuster, *Astrophysical Journal*, 21, 1, 1905. Abbot, in his valuable book *The Sun* (1911), also introduces molecular scattering as a principal agent in producing the appearance of the photosphere.

[2] A full comparison of the theoretical with the observational irradiation surfaces for different wave-lengths will be given at a later date. If 2 may be neglected as compared with $sz \sec \theta$, the expression for J becomes $J = J_0 \frac{2}{sz} \cdot \cos \theta$, which represents a sphere, tangent to the photospheric level in M. The irradiation surface, as constructed with the values for violet light taken from H. C. Vogel's well-known table (*Ber. der Berl. Akad.*, 1877, p. 104), is in its main part strikingly similar to such a sphere.

If, therefore, we consider both scattering and irregular refraction effects, the conclusions to which the theory leads are compatible with the observed shape of the irradiation surface, or with the distribution of the intensity on the solar disk.

The agreement also prevails when kinds of light of different wave-lengths are considered. Let us distinguish between, e.g., red and violet, by introducing the subscripts r and v.

At the center of the disk ($\theta=0$) we have between the intensities of red and violet light the proportion

$$p_0=\frac{J_r}{J_v}=\frac{J_{0,r}}{J_{0,v}}\cdot\frac{2+s_v z}{2+s_r z},$$

in which, according to Rayleigh's formula, $s_v>s_r$ (if cases of anomalous dispersion be excluded, so that the disparity between n_v and n_r may be neglected).

At a point, corresponding to the angle θ, we have

$$p_\theta=\frac{J_{0,r}}{J_{0,v}}\cdot\frac{2+s_v z\sec\theta}{2+s_r z\sec\theta}.$$

The second factor of p_0 is greater than unity, and p_θ is greater than p_0. This means that the longer waves preponderate as we proceed from the center of the disk outward. With increasing values of sec θ, $p\theta$ approaches the limit

$$p_{90°}=\frac{J_{0,r}}{J_{0,v}}\cdot\frac{s_v}{s_r}=\frac{J_{0,r}}{J_{0v}}\cdot\frac{\lambda_r^4}{\lambda_v^4};$$

this proportion, however, will be more or less modified by irregular refraction.

Taking all in all, the above theory of the photosphere thus appears to account for the sun's edge, and for the principal features of the results of Vogel's well-known spectrophotometric measurements.

It implies at the same time an interpretation of the *granular structure* of the solar disk. If Anderson[1] and other astrophysicists were right in assuming the irradiation surface of a point M near the photospheric level to be a hemisphere (sps_1 in Fig. 1, p. 131), irregular gradients of optical density could not produce any sensible dis-

[1] *Astrophysical Journal*, **31**, 166, 1910.

turbance in the uniform brightness of the disk, except in special cases. But their assumption certainly is erroneous; the average intensity of the light passing through M varies considerably with the value of the angle θ; so the irregular refraction of the light must result necessarily in variegation of luminosity.

Waves that undergo anomalous refraction will of course deviate to a higher degree in the same gradients. Following out this line of thought, we arrive at explanations of spectroheliograph results,[1] on which we shall not now insist.

A few remarks may be added in connection with the sun-spot hypothesis suggested in 1909.[2] A spot was supposed to be a region where, from a central minimum outward, the optical density increases with a gradually decreasing gradient. If sun-spots are solar vortices, such conditions are very likely to obtain. It was then argued that, when a similar structure is traversed by the light from an extensive source radiating, as the photosphere does, with intensities decreasing from the center toward the limb, refraction must exactly produce the characteristic optical features observed in a spot: an umbra surrounded by a penumbra. Taking anomalous dispersion effects into consideration, one is led by the same argument to an explanation of the principal properties of the spot-spectrum. Lately we succeeded in realizing, in the laboratory, the formation of a typical "sun-spot" by refraction of light in a whirling mass of gas, and could witness several phenomena rather closely resembling the appearances produced by the real solar objects. A description of those experiments, together with a discussion of their possible bearing on several spot-problems (e.g., on the apparent effect of the earth on the formation and growth of sun-spots), must be deferred to a separate paper.

We now only wish to emphasize that the above conception of sun-spots naturally fits in with our dioptrical explanation of the photosphere. The levels where vortex-motion should occur so as to produce the appearance of a spot will be found somewhere between spheres corresponding to PP and QQ of our Fig. 2. The conditions in a spot need not differ very much from those obtaining

[1] Cf. *Astrophysical Journal*, **21**, 278, 1905; **28**, 360, 1908; **31**, 419, 1910.

[2] *Proc. Roy .Acad. Amst.*, **12**, 273, 1909; *Physik. Zeitschr.*, **11**, 62, 1910.

in the surrounding regions. Their chief characteristics are: (1) the rotary motion, which determines a magnetic field and a systematic arrangement of density-gradients (that need not be steeper than the average irregular gradients otherwise present in the same levels), and (2) the differences of temperature and of composition connected with the special form of circulation.

SUMMARY

Various views concerning the nature of the photosphere are criticized, and a new dioptrical interpretation of several photospheric phenomena is proposed.

UTRECHT
May 1913

A FURTHER CONTRIBUTION TOWARD THE ESTABLISHMENT OF A NORMAL SYSTEM OF WAVE-LENGTHS IN THE ARC SPECTRUM OF IRON

By F. GOOS

1. *The aim of this article* is to point out again that for the establishment of a normal system of wave-lengths in the arc spectrum of iron, like that which has been adopted by the International Union for Solar Research, it is not sufficient to prescribe a current of 5 to 10 amperes[1] for the arc, but is absolutely necessary to define exactly the manner of burning and the part of the arc used.

By way of proof, the difference in the values of the three observers of the normals of the second order will be pointed out; the wave-lengths of the iron arc already published by Kayser[2] and by myself[3] will be compared with the measurements of St. John and Ware[4] which have recently appeared; and measurements of the widths of some selected iron lines will be given. Further, in conclusion, I shall offer suggestions as to an iron arc which will be as satisfactory as possible.

On the basis of their measurements made in Pasadena and on Mount Wilson, where the difference in altitude corresponds to a difference in barometric height of about $\frac{1}{8}$ atmosphere, St. John and Ware conclude that in the choice of standard lines, the extent to which the lines are sensitive to pressure must be carefully investigated, since especially in the less refrangible part of the spectrum the pressure-shifts reach values which cannot be ignored in observatories at high altitudes.

My observations with different sorts of iron arcs now show that, with the same external pressure—atmospheric pressure—on plates from different parts of one and the same arc, further by

[1] *Trans. Internat. Union for Solar Research*, **1**, 238, 1906.

[2] *Zeitschr. f. wiss. Phot.*, **9**, 173, 1911.

[3] *Ibid.*, **11**, 1, 1912; *Astrophysical Journal*, **35**, 221, 1912; *Zeitschr. f. wiss. Phot.*, **11**, 305, 1912; *Astrophysical Journal*, **37**, 48, 1913.

[4] *Astrophysical Journal*, **36**, 14, 1912.

change of current, arc length, etc., line-shifts occur which are of the same order of magnitude as those observed by St. John and Ware. I would like to offer as a hypothesis at this point that these shifts are due in part to pressure differences; that higher pressures prevail at the negative pole than in the middle of the arc and at the positive pole; and that with larger currents the pressure within the arc increases. This is because with larger currents more iron vaporizes, the vapor-density becomes greater, and a pressure arises in the inner parts of the arc.

2. *Normals of the second order.*—St. John and Ware in their work come to the conclusion that the international normals of the second order form a homogeneous system to within 0.001 Å. This is perhaps the case, but it seems strange that the values of the three different observers, the means of which form the international values, show systematic differences with respect to each other of several thousandths of an Ångström unit.

I believe that these differences are due to the fact that the three observers worked with different sorts of iron arcs. Fabry and Buisson used iron rods 7 mm thick, 3 to 5 amperes, and 110 or 220 volts; Eversheim 8 mm rods, 5 amperes, and 220 volts, while Pfund probably used the arc described by him,[1] with a small iron sphere as the positive electrode, 3.5 amperes and 220 volts. Eversheim, then, worked with larger currents than Fabry and Buisson and Pfund. But the larger current probably caused a higher pressure and in general shifted the lines toward the red. If now we make use of the observations of Gale and Adams[2] on the pressure-shifts in the iron spectrum, we see that all lines do not suffer the same shift, but that they may be divided into several groups of different susceptibility to pressure.

In Table I are collected, for the normals of the second order, the values of Fabry and Buisson, Eversheim, and Pfund;[3] the classification of Gale and Adams together with the shift for an increase in pressure of 8 atmospheres (Δ), and the differences, Eversheim−Fabry and Buisson, and Eversheim−Pfund.

[1] *Zeitschr. f. wiss. Phot.*, **6**, 326, 1908.

[2] *Astrophysical Journal*, **35**, 10, 1912.

[3] *Ibid.*, **32**, 215, 1910; **33**, 85, 1911.

TABLE I

λ	Fabry and Buisson	Eversheim	Pfund	Group	Δ (8 Atm.)	Eversheim—F. and B.	Eversheim—Pfund
	I.Å.	I.Å.	I.Å.		Å.	Å.	Å.
5371	.498	.493	.494	*a*	0.029	−0.005	−0.001
5405	.780	.780	.780		27	0	0
34	.530	.524	.528		27	− 6	− 4
55	.616	.611	.614		29	− 5	− 3
97	.521	.523	.523		30	+ 2	0
5506	.783	.785	.784		0.031	+ 2	+ 1
6027	.059	....	.059	*b*	0.062	....	....
65	.493	.493	.491		77	0	+ 2
6137	.700	....	.702		78	....	....
91	.569	.568	.567		86	− 1	+ 1
6230	.732	.736	.735		70	+ 4	+ 1
65	.147	....	.143		70	....	....
6318	.029	.028	.026		80	− 1	+ 2
35	.343	.342	.337		74	− 1	+ 5
93	.612	.613	.612		72	+ 1	+ 1
6430	.859	.862	.855		68	+ 3	+ 7
94	.994	.994	.992		0.065	0	+ 2
5232	.958	.958	.956	*d*	0.11	0	+ 2
66	.568	.569	.569		13	+ 1	0
5324	.196	.196	.195		12	0	+ 1
5569	.632	.636	.631		14	+ 4	+ 5
86	.770	.773	.772		12	+ 3	+ 1
5615	.658	.662	.663		13	+ 4	− 1
58	.835	.838	.835		0.15	+ 3	+ 3

If we take the means of the three groups, we get:

	Eversheim—F. and B.	Eversheim—Pfund	Δ (8 Atm.)
Group *a*	−0.0020 Å.	−0.0012 Å.	0.029 Å.
b	+0.0006	+0.0026	0.073
d	+0.0021	+0.0016	0.125

Even though these numerical values cannot be regarded as at all reliable, as a glance at the separate values of the differences Eversheim—Fabry and Buisson and Eversheim—Pfund shows, nevertheless, I believe that the signs at least are correct; that is, that for the two groups *b* and *d*, which are shifted to the red by pressure more strongly than group *a*, the wave-lengths of Eversheim are relatively larger than those of Fabry and Buisson and of Pfund, corresponding to the larger current with which Eversheim operated his arc. In the case of group *a*, the sign ought

really to be positive since there is a small shift toward the red in the case of this group also. The negative sign indicates that other systematic differences exist among the observers in addition to the pressure differences, which are to be sought for perhaps in the measurement itself, perhaps in a comparison of the light sources. But even group *a* is not very satisfactory in the agreement of the separate values, Eversheim—Fabry and Buisson, so that no definite conclusions may be drawn from it. As I shall point out later, the differences in wave-length, which are found in arcs burning very differently, correspond to a pressure difference of about $\frac{1}{3}$ of an atmosphere. I would estimate the pressure difference between the arc of Eversheim and that of Fabry and Buisson, and of Pfund to be $\frac{1}{5}$ atmosphere at most. Now Gale and Adams showed that at 8 atmospheres the lines of group *d* suffer a shift of 0.096 Å., relative to the lines of group *a;* that is, a shift of 0.0024 Å. for a pressure of $\frac{1}{5}$ atmosphere (in case the law of proportionality holds). We arrive thus at values which agree well in order of magnitude with those found above. In spite of the differences among the three separate observers, each of the three wave-length systems forms for itself a homogeneous system with respect to each of the iron arcs which was used. Thus the mean of the three, the system of international normals of the second order, forms a homogeneous system with respect to the iron arc whose properties are a mean of those used by the three observers. For any other arc, for example, one carrying 6 to 10 amperes, the system will no longer be homogeneous.

If, now, normals of the third order are derived from normals of the second order, the greatest possible care must be taken to use always exactly the same light-source from which the normals of the second order were obtained; for in the iron spectrum there are many lines even more sensitive to pressure than those listed above, but which cannot be well dispensed with as normals of the third order (contrary to the opinion of St. John and Ware, who would exclude these lines). Otherwise there exist wave-length differences, as the measurements of Kayser, of St. John and Ware, and of myself show both in comparison with one another, and with the normals of the second order.

Naturally, it is not easy to specify afterward for just what arc the International System of the second order holds, but I believe that it would be an iron arc carrying about 4 amperes, drawn out moderately long (about 5 mm) and of which only the central part was used. At any rate, the outstanding discrepancies among normals of the second order will scarcely amount to 0.001 Å. with this arc. But this degree of exactness may just about be obtained for the best lines, in determining the normals of the third order with gratings.

3. *Normals of the third order.*—At the time when I published my measurements in the less refrangible part of the spectrum, it was not possible to compare my wave-lengths with Kayser's in an entirely satisfactory way, since I could not isolate the systematic errors in Kayser's values, in order to investigate the outstanding errors, the source of which was unknown to me at that time. I believe that it has now become possible to do this. I will at any rate again assume in what follows, that differences in pressure exist in different sorts of arcs which are in the main responsible for the wave-length differences. Now there are, as we see from the measurements of Gale and Adams, and St. John and Ware, two large regions in the green and red where all the normals of the second order belong to the same group, with respect to pressure-shift, and where in addition several other lines are present which have been measured as normals of the third order by Kayser, by St. John and Ware, and by myself. There are from λ 5371 to λ 5535, 10 lines of group *a*, and from λ 6027 and λ 6494, 21 lines of group *b*. In addition, there is a third such region between λ 5569 and λ5658 to which the lines of sub-group *d* (according to St. John and Ware) belong. This group seems to me to be not entirely free from objection (as indeed the differences Pasadena —Mount Wilson show) since its susceptibility to pressure is considerable while that of groups *a* and *b* is very much less.

Within the limits of groups *a* and *b* there should, then, be no systematic differences among the observers, Kayser, St. John and Ware, and myself, or if they exist, they are attributable to another cause. Table II gives the differences Pasadena—Kayser, and Pasadena—Goos, for groups *a* and *b*.

As we see, the differences Pasadena—Goos show a small systematic

range, for which I can offer no explanation at this time.′ The differences Pasadena—Kayser are somewhat larger and are perhaps to be attributed to Kayser's systematic errors, mentioned previously[1] by me. A graphical adjustment yields the following corrections (Table III) which must be applied to Kayser's values and to mine to make them comparable with the Pasadena values.

TABLE II

λ	Group	Pasadena −Kayser	Pasadena −Goos	Δ 8 Atm.	λ	Group	Pasadena −Kayser	Pasadena −Goos	Δ 8 Atm.
I.Å.		Å.	Å.	Å.	I.Å.		Å.	Å.	Å.
5371.5		+0.005	0.000	0.029	6027.1		−0.003	+0.002	0.062
5405.8		+ 2	0	27	65.5		+ 3	0	77
29.7		+ 1	+ 2	29	6136.6		− 2	+ 4	82
34.5		+ 2	+ 3	27	37.7		− 2	0	78
46.9	*a*	+ 1	− 5	31	57.7		− 9	− 5	41
55.6		− 2	....	29	73.3		− 9	− 6	67
97.5		+ 1	0	30	91.6		0	− 1	86
5501.5		0	− 4	30	6200.3		− 8	− 2	79
06.8		+ 1	0	31	13.4		− 1	− 10	72
35.4		− 1	0	34	19.3		− 2	− 7	73
					30.7	*b*	0	+ 2	70
			Mean	0.030	52.6		+ 2	+ 3	77
	For λ 5371–λ 5429 mean			0.028	54.3		− 2	− 4	64
					65.1		0	− 1	70
					97.8		− 4	− 3	68
					6318.0		− 3	0	80
					35.3		+ 2	0	74
					93.6		0	+ 1	72
					6421.4		+ 9	− 3	68
					30.9		+ 11	− 1	68
					95.0		− 1	+ 1	65
								Mean	0.071
						For λ 6027–λ 6136 mean			0.074
						For λ 6136–λ 6421 mean			0.072

After applying these corrections, let us compare the Pasadena values with Kayser's and with mine for a few other lines within the limits mentioned above. There are between λ 6147 and λ 6411, 11 lines of group *d* which lie between normals of the second order belonging to group *b*. Moreover between λ 5383 and λ 5424, there are 4 lines of group *e* (shifted to the violet by pressure, according to St. John and Ware) which lie between normals belonging to

[1] *Zeitschr. f. wiss. Phot.*, **10**, 200, 1911.

group *a;* and between λ 6042 and λ 6078, there are three lines of group *e* which lie between normals belonging to group *b*.

TABLE III

From λ to λ	Correction Kayser	From λ to λ	Correction Goos
	Å.		Å.
5370–5400	+0.003	5370–5460	0.000
5400–5420	+ 2	5460–5540	− 1
5420–5450	+ 1		
5450–5540	0		
6020–6090	0	6020–6040	+ 1
6090–6110	− 1	6040–6080	0
6110–6130	− 2	6080–6110	− 1
6130–6140	− 3	6110–6320	− 2
6140–6160	− 4	6320–6410	− 1
6160–6180	− 5	6410–6500	0
6180–6200	− 4		
6200–6230	− 3		
6230–6260	− 2		
6260–6330	− 1		
6330–6360	0		
6360–6380	+ 1		
6380–6410	+ 2		
6410–	+ 3		

Table IV gives the required data. Under Δ are the pressure-shifts of Gale and Adams for 8 atmospheres, under Δ_1, the pressure-shift for $\frac{1}{8}$ atmosphere difference of pressure as found by St. John and Ware, through their measurements in Pasadena and on Mount Wilson.

The differences Pasadena—Kayser are in general positive. The mean of the 11 values is +0.001 Å. The value −0.012 for λ 6400 is quite exceptional, and if it were omitted, the mean would be +0.002 Å. The differences Pasadena—Goos are very irregular, but in general the negative values are larger than the positive ones, and the mean is −0.002 Å. If these differences are regarded as due to pressure-shifts, it means that Kayser worked with an arc of lower internal pressure than the Pasadena observers, and Goos, on the contrary, with one of higher pressure. The differences Pasadena—Goos especially, on account of their large variation, do not seem to me to be sufficiently well explained on the ground of

pressure alone. The accidental errors are not so large, as is shown by Table II for the lines of the *b* group in this spectral region. We must therefore assume that there are other factors which can influence the position of these lines.

TABLE IV

λ	Pasadena	Kayser	Goos	Pasadena −Kayser	Pasadena −Goos	Group	Δ For 8 Atm.	Δ_1 for ½ Atm.
	I.Å.	I.Å.	I.Å.	Å.	Å.		Å.	Å.
6147	.844	.840	.844	+0.004	0.000			+0.008
51	.636	.629	.631	+ 7	+ 5			+ 8
80	.225	.226	.216	− 1	+ 9			+ 9
6232	.669	.667	.671	+ 2	− 2			+ 7
46	.350	.343	.349	+ 7	+ 1	*d* Shifted to the red by pressure	0.28	+ 13
6301	.531	.527	.529	+ 4	+ 2		0.25	+ 13
02	.520	.521	.523	− 1	− 3			+ 9
36	.851	.850	.854	+ 1	− 3		0.26	+ 8
6400	.026	.038	.035	(− 12)	− 9		0.24	+ 6
08	.044	.047	.057	− 3	− 13			+ 6
11	.678	.676	.685	+ 2	− 7		2.23	+ 10
			Mean	+0.001	−0.002		0.25	+0.009
λ 6400 omitted mean				+0.002				
5383	.353	.363	.353	− 10	0			− 18
5410	.890	.904	.878	− 14	+ 13			− 21
15	.175	.186	.170	− 11	+ 5			− 20
24	.038	.051	.033	− 13	+ 5			− 22
			Mean	−0.012	+0.006	*e* Shifted to the violet by pressure	Unmeasurable Mean	−0.020
6042	.083	.092	.084	− 9	− 1			− 10
55	.983	.992	.980	− 9	+ 3			− 12
78	.470	.476	.466	− 6	+ 4			− 12
			Mean	−0.008	+0.002		Mean	−0.011

The situation is easier to interpret for the lines of the *e* group. For four lines in the green the mean Pasadena−Kayser is −0.012 Å., and Pasadena−Goos is +0.006 Å. For three lines in the red the corresponding means are −0.008 Å. and +0.002 Å. There can be no doubt of a decided systematic difference here. Regarded as pressure-shifts, they indicate as above that lower pressures existed in Kayser's arc, and higher pressures in mine than in the arc used by St. John and Ware. This is also in harmony with the data of the observers. St. John and Ware worked with the Pfund arc, at 6 amperes and 110 volts, and thus in any

case, of moderate length; Kayser used about the same currents, always with a very long arc, in order to be able to cover the long slit of his concave grating. I myself used an arc at 6 or 7 amperes, taken especially short, since it then burns very quietly and with great brilliancy. All observations (I shall take this up again later) point to the conclusion that in the middle portion of a long arc, with its sharp fine lines, the pressure is less than in a short arc which shows diffuse and greatly broadened lines. If we compute the amount in atmospheres by which the pressure is greater than and less than the Pasadena pressures, from the systematic line-shifts of groups *d* and *e*, with the aid of the values Δ and Δ_1, we get the following table. (It should be noted that $\Delta = 0.25$ Å. is the absolute shift for a pressure of 8 atmospheres, while we are dealing here with the relative shifts with respect to the normals of the second order which belong to the group *b*, $\Delta = 0.072$.)

TABLE V

Group	Kayser	Goos
d	From Δ decrease in pressure $\frac{1}{11}$ Atm.	From Δ increase in pressure $\frac{1}{11}$ Atm.
	From Δ_1 decrease in pressure $\frac{1}{23}$ Atm.	From Δ_1 increase in pressure $\frac{1}{23}$ Atm.
e green	From Δ_1 decrease in pressure $\frac{1}{8}$ Atm.	From Δ_1 increase in pressure $\frac{1}{17}$ Atm.
e red	From Δ_1 decrease in pressure $\frac{1}{7}$ Atm.	From Δ_1 increase in pressure $\frac{1}{25}$ Atm.

The value $\frac{1}{11}$ atmosphere deduced for group *d* from Δ is in any case not free from objection and is too large, since many of the lines of this group could not be measured by Gale and Adams at 8 atmospheres pressure and showed a greater susceptibility to pressure than corresponds to the accepted mean value of 0.25 Å. The value deduced for the three groups, *d*, *e* green, and *e* red, from Δ_1 agree fairly well. The means give for Kayser a diminution of pressure of $\frac{1}{10}$ atmosphere, and for Goos an increase in pressure of $\frac{1}{21}$ atmosphere as compared with Pasadena.

The assertion above, that in the middle portion of a long arc the pressure is less than in a short arc, I shall support by two series of measurements (which were published in my last article). Plane grating measurements on an arc 3 mm long were compared with Fabry-Perot interferometer measurements on the middle part of

an arc 10 mm long; further, concave grating measurements, which I was able to make with Kayser's large grating during the course of a visit at Bonn, on an arc 3 to 4 mm long were compared with measurements on an arc 8 to 9 mm long. The current was, in all cases, 6 to 7 amperes.

TABLE VI

λ	Arc 3 mm	Arc 10 mm	Diff.	Group	λ	Arc 3–4 mm	Arc 8–9 mm	Diff.	Group
	I.Å.	I.Å.	Å.			I.Å.	I.Å.	Å.	
5371	.495	.498	+0.003	*a*	5554	.872	.893	+0.021	*e*
5410	.878	.915	+ 37	*e*	65	.689	.704	+ 15	*e*
15	.170	.203	+ 33	*e*	69	.632	.632	0	*d*
24	.033	.066	+ 33	*e*	72	.852	.856	+ 4	*d*
34	.526	.529	+ 3	*a*	76	.100	.104	+ 4	*d*
97	.522	.518	− 4	*a*	86	.773	.772	− 1	*d*
					98	.288	.307	+ 19	*e*
					5602	.961	.964	+ 3	*d*
					15	.659	.660	+ 1	*d*
					24	.559	.558	− 1	*d*
					38	.279	.272	− 7	*d*
					58	.837	.836	− 1	*d*

In the region from λ 5371 to λ 5497, the normals of the second order which served as reference lines belonged to group *a*, the other three lines to group *e*. These show a shift 0.034 Å. to the violet in the middle of the 3 mm arc, which according to St. John and Ware corresponds to an increase in pressure of $\frac{1}{3}$ atmosphere. In the region from λ 5554 to λ 5658, the lines λ 5569, λ 5586, λ 5615, and λ 5658, which belong to group *d*, were used as reference lines. Of the remaining 8 lines, 5 belonged to group *d* and should show no pressure-shift (in the mean, the difference for these lines is −0.001 Å.). The three remaining lines, which belong to group *e*, on the contrary, show in the mean a shift of 0.018 Å. to the violet, which corresponds to an excess of pressure in the short arc, compared to the long arc, of $\frac{1}{6}$ atmosphere.

4. *Breadth of lines.*—Another phenomenon is closely allied to pressure-shift, namely, the broadening of the lines. It is to the point, therefore, to measure the width of lines in different parts of the arc, and at different current strengths. A Fabry-Perot interferometer, with adjustable distance between the plates, is convenient for this,

and I have constructed one of simple form[1] for this purpose. The more homogeneous the radiation, the clearer the fringes, and they become weaker with increasing distance between the plates, and finally disappear for a certain difference of path, D, equal to twice the distance between the interferometer plates. From this limiting distance D one may get a measure of the width of the lines by the relation $d\lambda=\frac{\lambda^2}{D}$ (Fabry and Buisson).[2] The width of the line would be given directly by $d\lambda$, if the line had sharp edges, i.e., if it were a sharply defined region from λ to $\lambda+d\lambda$, and in case the apparatus were perfect. In spite of the fact that these conditions are not fulfilled, and that we are dealing in part with very diffuse lines, which one can hardly regard as having a definite width, I shall, in what follows, call $d\lambda$ the width of the lines.

Table VII refers to an arc 5 mm long, between two iron poles 7 mm in diameter, and carrying a current of 5.6 amperes. The potential of the current was 220 volts, the fall of potential across the arc, 49 volts. The negative pole was above. I have determined, visually, the width of 25 lines in five different zones of this arc. For the finest lines, a path difference, D, of more than 45 mm was required, before the interference-fringes disappeared.

The separate zones are circular surfaces 1 mm in diameter. Zone 1 lies immediately at the negative pole, zone 3 in the middle of the arc, and zone 5 at the positive pole.

The lines are again arranged in groups according to their susceptibility to pressure. An increase of width at the negative pole is shown for all the lines. It appears also that with groups *d* and *e* there is a slight increase at the positive pole, but the observations here are difficult on account of the diminished brightness of the lines. Immediately at the negative pole, the mean width of the lines of group *a* is 0.07 Å., of group *d* 0.14 Å., of group *e* 0.33 Å. The pressure-shift per atmosphere for these groups is +0.004 Å., +0.02 Å., and −0.06 Å.

I have also determined the width of a few very sensitive lines which apparently all belong to group *e*, for different current

[1] *Zeitschr. f. Instrumentenkunde*, **32**, 326, 1912.

[2] *Astrophysical Journal*, **31**, 115, 1910.

strengths, using a very short arc, with the iron pole-pieces separated only 1 mm. The results are collected in Table VIII.

I used again a 220-volt circuit. The potential difference at the electrodes is given in the table. For currents of 4.5 and 6 amperes I have given two sets of observations, one with iron poles

TABLE VII

λ	−Pole ←«« Zone »»→ Pole+					Group
	1	2	3	4	5	
I.Å.	Å.	Å.	Å.	Å.	Å.	
5341.0	0.06	0.06	0.06	0.06		
71.5	9	6	6	6		
97.1	9	9	6	< 6		
5405.8	6	6	6	6	<0.06	
29.7	9	6	< 6	< 6	< 6	a
34.5	6	6	< 6	< 6	< 6	
46.9	9	6	< 6	≤ 6	< 6	
97.5	6	< 6	< 6			
5501.5	6	6	< 6			
06.8	6	< 6	< 6			
Mean	0.07	0.06	0.05	0.05	0.05	
5324.2	13	6	6	6	9	
39.9	9	6	6	6		
93.2	13	6	9	6	9	
5569.6	10	7	7			
72.8	10	7	7			
76.1	14	7				d
86.8	14	7	< 7	7	< 10	
5603.0	14	10				
15.7	14	10	< 7	7	< 10	
24.6	17	10				
58.8	17	< 10				
Mean	0.14	0.08	0.07	0.06	0.09	
5383.4	25	18	13	13	18	
5410.9	36	13	13	13	18	e
15.2	36	26	13	13	18	
24.0	36	26	18	18	18	
Mean	0.33	0.21	0.14	0.14	0.18	

5 mm and one with iron poles 9 mm in diameter. As we see, at 4.5 amperes the width of the line is somewhat less for the 9 mm poles than for the 5 mm poles; but using a current of 6 amperes there is scarcely any difference. It was not possible to get a satisfactory arc with 3 amperes and 9 mm poles or with 9 amperes and 5 mm

poles, in the first case on account of the weakening of the light, and in the second on account of the melting of the iron. In the mean we get for 3, 4.5, 6, and 9 amperes line widths of 0.31, 0.38, 0.46,

TABLE VIII

λ	3 Amp. 36 Volts 5 mm	4.5 Amp. 33 Volts 5 mm	4.5 Amp. 34 Volts 9 mm	6 Amp. 32 Volts 5 mm	6 Amp. 33 Volts 9 mm	9 Amp. 31 Volts 9 mm
I.A.	Å.	Å.	Å.	Å.	Å.	Å.
5367.4	0.32	0.48	0.36	0.48	0.48	0.71
69.9	32	48	36	48	48	71
83.4	29	36	29	48	48	71
5404.0	27	32	26	36	42	59
10.9	29	42	33	45	42	59
15.2	33	42	42	49	49	72
24.0	37	49	42	49	49	72
Mean	0.31	0.42	0.35	0.46	0.47	0.68

and 0.68 Å. This relation between width of line and current may be expressed very well by the equation

$$d\lambda = 0.28 + 0.005\, i^2 \ .$$

The breadth $d\lambda$, computed by this formula for the current strengths i, are 0.32, 0.38, 0.46, and 0.68 Å. This formula also shows that the width is a function of the square of the current strength, and that for lines of group e, with an arc 1 mm long, even with very small currents, the average width $d\lambda$ does not fall below 0.28 Å.

TABLE IX

λ	9 Amp. 40 Volts, 9 mm Poles		
	−Pole	Center	+Pole
I.A.	Å.	Å.	Å.
5367.4	0.48	0.29	0.32
69.9	48	32	32
83.4	41	26	24
5404.0	37	27	24
10.9	37	27	24
15.2	42	33	29
24.0	49	37	33
Mean	0.43	0.30	0.28

In conclusion, the widths of the same lines are given in Table IX for three zones (at the negative pole, in the middle and at the posi-

tive pole,) using an arc 3 mm long and a current of 9 amperes between iron poles 9 mm in diameter.

We see that even immediately at the negative pole itself the width is not nearly so great as in the arc 1 mm long.

The whole investigation shows us again that the iron arc is not homogeneous. Groups of lines exist which change their widths in different ways, both within one and the same arc, and when arc length and current strength are changed. These groups are the same which are concerned in pressure susceptibility. Within the different sorts of arcs, pressure differences exist which produce the same effect as increased or diminished external pressure.

5. *Suggestions for the determination of normals of the third order.*—All of the measurements of normals of the third order which have been published up to the present time show the inadequacy of the specifications for the iron arc. The iron arc is not homogeneous in itself; radiations from different parts of the arc give different results, and length of arc and current strength are influential to a high degree. First of all, the lack of symmetry of the arc is very disturbing. While the conditions appear to change but little from the middle of the arc to the positive pole, a very significant broadening of the lines is perceived from the middle of the arc toward the negative pole. I believe that this lack of symmetry may best be rendered harmless by reversing the current, having the positive pole below for half the time, and the negative for the other half. It is very important also, that the arc burn quietly, be as bright as possible, but still furnish sufficiently sharp lines. On the basis of the many experiments which I have tried, and especially in view of what I have said in regard to the normals of the second order, I should like to propose that in the future for the normal spectrum of iron, an arc 5 mm long (separation of the rounded ends from each other) be used, between iron rods 6 mm in diameter, and with a current of 4 amperes. It should be used on a 220-volt circuit; the potential difference at the arc then falls to between 45 and 49 volts. It should be used with a pole changer, and the arc so projected on the slit of the spectrograph with the condensing lens that only a portion of the arc at the middle is used extending 1.5 mm vertically at most.

The difficulty of meeting this condition with the concave grating, as ordinarily mounted, should also be pointed out here. On account of the astigmatism it is only with difficulty that light from a prescribed portion of the arc can be isolated. Moreover, in consequence of the astigmatism, a long slit is required, which can be covered with the short middle portion of the arc only with the aid of a lens of very large angular aperture. It would perhaps be advantageous in work demanding the highest degree of exactness, to mount the concave grating "non-astigmatically," with the aid of a collimator (concave mirror) as Runge and Paschen,[1] and Fabry and Buisson[2] have already done. You get then, to be sure, only half the dispersion, though naturally the same resolving power, but in consequence you have on a plate of given length twice as many normals of the second order, making a better comparison possible, and have the great advantage of a fourfold light-intensity. The spectrum is normal within the same limits as in Rowland's mounting, but the constant varies somewhat in different parts of the spectrum.

TABLE X

	λ_o	λ_u	$\lambda_o-\lambda_u$	$\frac{\lambda_o+\lambda_u}{2}$	λ_m	$\lambda_m-\frac{\lambda_o+\lambda_u}{2}$	Group
	I.Å.	I.Å.	Å.	I.Å.	I.Å.	Å.	
5371	.492	.493	−0.001	.493	.495	+0.002	*a*
5405	.782	.782	0	.782	.780	− 2	*a*
10	.907	.900	+ 7	.903	.912	+ 9	*e*
15	.182	.182	0	.182	.190	+ 8	*e*
24	.050	.042	+ 8	.046	.056	+ 10	*e*
34	.525	.525	0	.525	.525	0	*a*
97	.524	.524	0	.524	.523	− 1	*a*

I have made some investigations on the homogeneity of the middle portion of an arc, like that described above, which burned excellently and was very bright. The lines of the *e* group are very good for this purpose; they are among the most sensitive in the whole spectrum. The whole length of the 5 mm arc was projected on the slit and afterward the spectrograms were measured at three different places: exactly in the middle (denoted in Table X by

[1] *Wied. Ann.*, **61**, 641, 1897.

[2] *Jour. de phys.*, IV, **9**, 929, 1910.

λ_m), 1.6 mm above the middle (λ_o), where the negative pole was during the first half of the exposure (three minutes) and the positive during the second half (three minutes); and finally, 1.6 mm below (λ_u).

As we see from the differences $\lambda_o - \lambda_u$, this arc also is not entirely symmetrical. This is because the bright flame which comes out from the negative pole, when the negative pole is below, stretches up in the form of a pointed flame, straight and long; when the negative pole is above, it is bent around by the hot-air streams and forced up. The differences $\lambda_m - \frac{\lambda_o + \lambda_u}{2}$ show the relative shifts of the three lines of group *e* with respect to the four lines of group *a* which served as standards. It is seen here also that the very sensitive lines of group *e* show systematic differences up to 0.01 Å., in moving 3.2 mm in a vertical direction. Within the previously prescribed limits of 1.5 mm, this would amount to only 0.003 Å. But it is now self-evident that the lines of group *e* must not be chosen as normals. With the other groups, particularly group *d*, the systematic differences will not amount to 0.002 Å.

In regard to the choice of normals of the third order, in opposition to the view of St. John and Ware, I am of the opinion that in addition to the lines of groups *a* and *b* (group *c* has no lines in this region) the lines of group *d* should also be included, since, without them, the intervals between the normals in many places become too large. It is naturally necessary then to reduce all observations to the normal atmospheric pressure of 760 mm, for which a knowledge of the pressure-shifts for a small reduction of pressure (in the range from about ½ to 1 atmosphere) is necessary. Whether the measurements of the normals of the third order published up to the present time form a really homogeneous system of normals for the less refrangible part of the spectrum appears to me very questionable. The best means for attaining this end would be, in any case, to prepare an entirely new series of observations with more uniform light-sources.

An important question still remains open, namely, how best to fill in the gap in the unusable yellow-red part of the iron spectrum. I have made many investigations of nickel but have been unable

to find any arc which burns well, neither a combined iron-nickel arc nor one between rods of nickel-steel (25 and 36 per cent). But entirely aside from this point, the nickel lines in and of themselves are not satisfactory, and are apparently very sensitive to pressure, so that this metal on this account is not suitable to furnish normals. A light-source must be found which not only fills up the gap in the iron spectrum from λ 5700 to λ 5900, but which extends to some distance on each side, in order that it may not be necessary in the limiting regions, to work with two comparison light-sources. It must then be a light-source which possesses a larger number of suitable lines between λ 5500 and λ 6100.

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THE ORBITS OF EIGHTY-SEVEN ECLIPSING BINARIES—A SUMMARY

By HARLOW SHAPLEY

The results which are catalogued and briefly summarized in the present communication have been obtained from an extensive study of all accessible published and unpublished observations of eclipsing variables. More than a hundred thousand light-measures have been discussed in detail, representing the photometric work of thirty observers on the light-curves of nearly a hundred stars. The observations have been made in many ways: with the sliding-prism polarizing photometer, with the meridian, selenium, Zöllner, and wedge photometers, by measures of extra-focal plates, by estimates on the Harvard photographs, and by Argelander's method of visual estimates. The new methods of obtaining orbits from light-curves have so greatly diminished the labor of computation that it has been possible to develop in a relatively short time this branch of double-star astronomy. The catalogue of orbits given below contains 87 systems—a number that compares favorably with the lists of orbits of spectroscopic binaries and of visual double stars. Two or more solutions were made for each system. Of the total of 199 orbits, two were computed by Dugan, two by Stebbins, three by Roberts, eight by Russell, and 184 by the writer. The reader is referred to papers published during the last year for the theory of the orbits of eclipsing stars, and for examples of the solution for well-observed stars with many different types of light-curves.[1] The detailed discussion of the observational and computational

[1] H. N. Russell, "On the Determination of the Orbital Elements of Eclipsing Variable Stars," *Astrophysical Journal*, **35**, 315, 1911, and **36**, 54, 1912; "Elements of the Variables *W Delphini*, *W Ursae Majoris*, and *W Crucis*," *ibid.*, **36**, 133, 1912; H. N. Russell and H. Shapley, "On Darkening at the Limb in Eclipsing Variables," *ibid.*, **36**, 239 and 385, 1912; H. Shapley, "Elements of the Eclipsing Variables *W Delphini*, *S Cancri*, *SW Cygni*, and *U Cephei*," *ibid.*, **36**, 269, 1912; "The Visual and Photographic Ranges and Provisional Orbits of *Y Piscium* and *RR Draconis*," *ibid.*, **37**, 155, 1913; "The Orbits of *RZ Ophiuchi* and *ε Aurigae* Treated as Eclipsing Binaries," *Astronomische Nachrichten*, **194**, 225 (1913).

work, together with the results of the statistical investigation of the orbits, is to appear as a publication of the Princeton University Observatory.

In a work of this kind the investigation of every star cannot, of course, be considered as exhaustive and definitive. I have not utilized all the existing observations of the variables considered, nor tried to harmonize, explain, and adjust non-homogeneous sets of measures. The computations for each star have been based on what appeared to be the most complete and reliable series of observations, generally the work of some one observer being used, but occasionally the combined results of two or more; and in many cases the work in whole or in part has been based on unpublished photometric observations of my own. Whenever a good series of photometric measures has been available, estimates made by the Argelander method have been rejected. I am under obligation to a number of astronomers for assisting me with this study in various ways, but particularly to Professor Russell, who has directed and encouraged the investigation throughout and has helped with the computations in many cases; to Professor Pickering and Miss Cannon, who generously put at our disposal extensive unpublished photometric data and made special investigations of the spectra of many stars; and to Professor Nijland, of Utrecht, who has sent in manuscript light-curves based on long series of observations of 35 eclipsing systems, nearly one-half of which were stars for which no other data would have been available.

The stars in the following table have been divided into three general classes. In each division I have attempted to arrange the individual systems in order of the completeness of the photometric data, rather than in order of the degree of determinateness of the orbit obtained. The classification and order can be only approximate; but in general, stars in the first group have been so well observed that further photometric work will not appreciably change the solutions; orbits in the second group are susceptible of more or less improvement, as they are based on observations that are not as complete or as accurate as might be desired; while in the third class are listed those stars for which the observational data are very meager and uncertain, but concerning whose light-

variations enough is known to make it possible to derive approximate orbits. Further observations will probably alter greatly some of the orbits in the third group. But certain factors in these systems (for instance, the most important one of all—the density) are derived with a precision sufficient to aid materially in the generic studies of eclipsing variables. The manuscript sent by Professor Nijland contains only the co-ordinates of smooth curves drawn to represent his series of observations at primary eclipse. The precision of the resulting orbits cannot be estimated without a knowledge of the accuracy with which the normal points are represented and of the uniformity of the distribution of the observations. Consequently I have placed all the orbits that depend only on the Nijland curves in a group by themselves, arranging them in order of number of observations involved. Doubtless some of the curves are of high accuracy, while others must be considered only provisional.

EXPLANATION OF THE TABLE OF ORBITS

Letters in column (3), indicating the observer, have the following significance (the complete bibliography will be given in the later publication):

B =Baker	L =Miss Leavitt	Ro =A. Roberts
C =Miss Cannon	Le =Lehnert	Se =Seares
D =Dugan	Lu =Ludendorff	Sh =Shapley
E =Enebo	Lz =Luizet	St =Stebbins
G =Graff	N =Nijland	Sw =Stratonow
H =Haynes	P =E. C. Pickering	W =Wendell
I =Ichinohe	Pa =J. A. Parkhurst	Wh =Miss Whiteside
In =Innes	Pr =Pračka	Wy =Wylie
J =Jordan	*r* =see remark	

Unpublished observations are indicated by "ms" in this column. In column (4) the period of revolution is rounded off to the third decimal place.[1] The magnitude at maximum is only approximate for most faint stars; its precise value is not important. The ranges, column (6), are "unrectified," that is, the variations due to

[1] For corrections to the light-elements of many stars, obtained during the course of the work, see *Popular Astronomy*, December 1912; March 1913; and *Astronomische Nachrichten*, **192**, 79, 1912. Also see note below on *RS Cephei*.

eclipse, ellipticity, and "reflection" are combined. The first number for each system pertains to primary minimum, and the second number to secondary minimum. When the secondary is computed, but has not been observed, the value is inclosed in brackets; when it is assumed for purposes of solution, it is in parentheses, and when observed, no brackets or parentheses are used. The computed secondary minima are always for "uniform" disks, the "darkened" values being about twice as great except where central transit restrictions exist. Spectra are taken from *H.A.*, **56**, VI, with many revisions and additions furnished by Miss Cannon. "*tf*" signifies "too faint to classify."

In the absence of definite knowledge concerning the degree of darkening toward the limb of the stellar disks, I have computed double sets of elements for all systems on the two extreme hypotheses of uniform disks and disks completely darkened at the edge. These solutions are designated by "U" and "D" in the eighth column. For some stars, for which the orbit is indeterminate between certain limits, I have given the limiting solutions, "uniform" or "darkened"; and for some (*RZ Cassiopeiae* and *U Coronae*, for instance), solutions depending on different assumptions concerning the secondary minimum. The units of light, length, and density are respectively the maximum light of the system, the radius of the relative orbit, and the solar density. L_b is the light of the brighter star; that of the fainter is $L_f = 1 - L_b$. Columns (10) and (11) contain r_b and r_f, the radii of the two components. When the stars are elliptical these columns contain their longest axes, a; the shorter equatorial axes, b, may be obtained from column (13), which contains b/a. Column (12) contains the cosine of the orbital inclination, that is, the projected distance of centers at the time of mid-eclipse. When $\cos i$ is given as (0) the assumption of a central eclipse was necessary—the elements that would naturally develop from the observations yielding an imaginary value of i. With the third-class stars, however, $\cos i = (0)$ often means that in the absence of a good light-curve the simpler solution of central transit was found to represent the observations satisfactorily. Columns (14) and (15) contain the densities of the brighter and fainter stars, computed in all cases on the assumption

CATALOGUE OF THE ORBITS OF ECLIPSING BINARIES

GRADE I. STARS WELL OBSERVED

No.	Star	Obs.	Period	Max.	Range	Sp.	Sol.	L_b	r_b	r_f	cos i	b/a	ρ_b	ρ_f	J_b/J_f
(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)	(12)	(13)	(14)	(15)	(16)
1	*Z Draconis*..........	D	1^d357	10^m46	2^m55	*lf*	U_1	0.911	0.217	0.270	0.074	0.986	0.36	0.19	15.8
					0.06		U_2	.886	.214	.270	.070	.990	.39	.19	12.3
							D_2	.927	.257	.262	.054	.997	.22	.21	13.1
2	*RT Persei*...........	D	0.849	10.62	1.37	F?	U_1	.861	.274	.274	.076	.980	.45	.45	6.2
					0.17		U_2	.849	.272	.272	.078	.980	.48	.48	5.62
							D_2	.879	.320	.256	.026	.987	.29	.57	4.64
3	*β Aurigae*...........	St	3.960	2.07	0.09	Ap	U	.50	.146	.146	.220	.990	.14	.14	1.0
					0.09		D	.50	.159	.159	.229	.993	.11	.11	1.0
4	*β Persei*............	St	2.867	2.2	1.22	B8	U_1	.898	.210	.239	.134	....	.088	.060	11.4
					0.06		U_2	.907	.208	.228	.121	....	.092	.070	11.6
							D_2	.926	.241	.229	.129	....	.060	.069	11.3
5	*RZ Centauri*.........	L	1.876	8.48	0.46	A	U_1	.74	.490	.245	.221	.896	.020	.16	0.7
					0.34		D_1	.74	.481	.226	.239	.935	.020	.19	0.6
							D_2	.82	.491	.233	.000	.940	.018	.17	1.0
6	*U Pegasi*............	W	0.375	9.32	0.60	F?	U_1	.57	.50	.50	.264	.887	....	....	....
					0.46		U_2	.603	.450	.450	.300	.770	.88	0.88	1.52
							U_3	.788	.544	.348	.223	.782	.49	1.86	1.52
							D_2	.603	.454	.454	.352	.858	.70	0.70	1.52
7	*WZ Cygni*............	Sh	0.584	9.9	1.45	A	U	.794	.455	.387	.058	.842	.30	.49	2.8
		ms			0.44		D	.794	.473	.369	.094	0.904	.23	.48	2.4
8	*S Cancri*............	W	9.485	7.98	2.12	A	U	.858	.075	.203	.119	....	.178	.009	44.0
					0.04:		D	.858	.096	.184	.080	....	.084	.012	22.0
9	*SW Cygni*............	W	4.573	9.06	2.66	A	U	.914	.131	.266	.110	....	.141	.017	43.0
					[0.02]		D	.914	.166	.247	.044	....	.070	.021	24.0
10	*U Cephei*............	W	2.493	6.78	2.39	A	U	.890	.205	.324	.000	....	.126	.032	20.0
					0.05:		D	.890	.219	.319	(0)	....	.104	.034	17.0
11	*W Delphini*..........	W	4.806	9.40	2.70	A	U	.917	.135	.256	.114	....	.118	.017	40.0
					[0.03]		D	0.917	0.170	0.241	0.068	....	0.060	0.021	22.0

12	*RZ Cassiopeiae*	PaJ	1.195	6.43	1.22	A	U_1:	1.00	0.273	0.257	0.118	....	0.24	0.28	∞
					(0.00)		U_2	0.913	.261	.269	.118	....	.27	.24	11.0
					or		D_1	1.00	.320	.256	.111	....	.14	.28	∞
					(0.07)		D_2	0.936	.313	.263	.106	....	.15	.26	10.0
13	*RX Herculis*	Sh	1.779	7.0	0.49	B9	U_1	.50	.190	.190	.084	....	.31	.31	1.0
		ms			0.49		U_2	.639	.213	.162	.051	....	.22	.50	1.0
							D_1	.50	.202	.202	.110	....	.26	.26	1.0
14	*V Serpentis*	L	3.454	9.52	0.94	A	U	.587	.185	.296	.131	.947	.099	.024	3.6
					0.24		D	.587	.224	.280	.098	.968	.053	.027	2.2
15	*U Sagittae*	W	3.381	6.43	2.76	B8	U	.921	.220	.291	.000	....	.055	.024	20.0
					[0.05]		D	.917	.238	.288	(0)	....	.043	.025	17.0
16	*RX Draconis*	HSh	3.786	10.20	0.50	F	U_1	.50	.099	.099	.037	....	.49	.49	1.0
		ms			0.50		U_2	.63	.111	.086	.024	....	.35	.75	1.0
							D_1	.50	.104	.104	.170	....	.42	.42	1.0
17	*u Herculis*	W	2.051	4.61	0.71	B3	U	.715	.312	.372	.249	.887	.067	.039	3.6
					0.24		D	.715	.308	.362	.278	.931	.064	.039	3.5
18	*U Ophiuchi*	PW	1.677	5.67	0.69	B8	U_1	.637	.224	.276	.048	.910	.14	.26	1.15
					0.59		U_2	.535	.252	.252	.079	.909	.18	.18	1.15
							D_2	.535	.252	.252	.109	.945	.17	.17	1.15
19	*ST Carinae*	L	0.902	9.31	0.87	A	U	.865	.273	.345	.245	....	.40	.20	10.3
					0.24		D	.868	.291	.363	.276	....	.33	.17	10.3
20	*RW Tauri*	Sh	2.769	8.05	3.42	B5	U_1	.957	.135	.254	.110	....	.36	.054	79.0
		ms			[0.02]		D_1	.957	.169	.241	.060	....	.18	.063	45.0
							U_2	.950	.136	.234	.084	....	.35	.069	56.0
21	*ZZ Cygni*	Sh	0.629	10.59	1.09	A?	U	.893	.287	.354	.215	....	.71	.38	12.7
		ms			0.06:		D_1	.918	.332	.357	.226	....	.46	.38	13.0
							D_2	.933	.361	.340	.197	....	.36	.43	12.3
22	*UW Cygni*	W	3.451	10.55	2.57	A?	U	.907	.175	.208	.000	....	.099	.063	13.0
					[0.08]		D	.907	.196	.209	.000	....	.075	.062	11.0
23	*R Canis Majoris*	W	1.136	5.38	0.60	F	U_1	.871	.346	.277	.220	....	.13	.25	4.3
					0.09		D_1	.782	.336	.336	.308	....	.14	.14	3.6
							U_2	.904	.266	.213	.140	....	.28	.55	6.0
							U_3	0.869	0.288	0.257	0.196	....	0.22	0.31	5.3

CATALOGUE OF THE ORBITS OF ECLIPSING BINARIES—*Continued*

No.	Star	Obs.	Period	Max.	Range	Sp.	Sol.	L_b	r_b	r_f	cos *i*	*b/a*	ρ_b	ρ_f	J_b/J_f
(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)	(12)	(13)	(14)	(15)	(16)
24	*W Ursae Majoris*....	r	0.334	7.91	0.60	G	U_1	0.760	0.431	0.242	0.143	0.757	1.32	7.39	1.0
					0.60		U_2	.500	.366	.366	.234	.745	2.22	2.22	1.0
							D_2	.500	.368	.368	.260	.850	1.72	1.72	1.0
25	*W Crucis*..........	L	198.5	8.90	0.60	Gp	U	.676	.520	.197	.150	.855	2×10^{-6}	3×10^{-5}	0.3
					0.28		D	.904	.613	.343	.247	.912	10^{-6}	5×10^{-6}	3.0
26	*RR Centauri*........	Ro	0.606	7.38	0.44	F	U	.563	.506	.506	.535	.631	0.35	0.35	1.3
					0.42		D	.574	.500	.500	.668	0.685	.31	.31	1.4
27	*RS Sagittarii*	Ro	2.416	6.10	0.74	A	U	.824	.324	.253	.076	....	.034	.071	2.85
					0.21		D	.813	.347	.277	.148	....	.028	.055	2.8
28	*S Velorum*..........	Ro	5.934	7.85	1.39	A	U	.722	.104	.230	.000	....	.170	.016	13.0
					[0.06]		D	0.722	0.121	0.233	(0)	....	0.106	0.015	9.6

GRADE II. STARS FAIRLY WELL OBSERVED

No.	Star	Obs.	Period	Max.	Range	Sp.	Sol.	L_b	r_b	r_f	cos *i*	*b/a*	ρ_b	ρ_f	J_b/J_f
29	*RW Monocerotis*.....	HSh	1.906	8.75	1.72	A	U	0.795	0.207	0.287	(0)	....	0.21	0.078	7.5
		ms			0.10:		D	.795	.218	.282	(0)	....	.18	.082	6.5
30	*V Puppis*...........	Ro	1.454	4.14	0.64	B1	U	.60	.456	.420	0.236	0.813	.051	.065	1.27
					0.53	B3	D	.60	.461	.420	.289	.885	.042	.055	1.24
31	*Y Piscium*..........	C	3.766	9.00	3.40	A	U	.975	.144	.240	.107	....	.157	.034	84.0
		ms			(0.01)		D	0.975	.178	.231	.075	....	.084	.038	66.0
32	*U Coronae*..........	W	3.452	7.52	1.18	A	U_1	1.00	.188	.265	.193	....	.084	.030	∞
					(0.00)		U_2	0.95	.183	.269	.189	....	.093	.029	37.0
					(0.02)		U_3	.86	.176	.274	.180	....	.103	.028	15.0
					(0.05)		U_4	.74	.167	.273	.148	....	.120	.028	8.0
					(0.10)		D_3	.83	.202	.273	.168	....	.069	.028	9.0
33	*SZ Centauri*	L	4.108	8.18	0.65	A	U_1	.59	.302	.242	.046	.933	.017	.032	0.9
					0.58		U_2	.626	.302	.242	.046	.933	.017	.032	1.1
							D	0.59	0.296	0.219	0.074	0.959	0.017	0.041	0.8

34	*Z Herculis*	W	3.993	7.10	0.80	F	U	0.508	0.097	0.207	0.110	....	0.45	0.047	4.7
					0.12		D	.570	.117	.217	.139	....	.26	.040	4.5
35	*U Scuti*	W	0.955	9.67	0.96	A	U	.900	.393	.295	.077	0.841	.17	.40	5.1
					0.30		D	.900	.418	.284	.121	.904	.12	.39	4.2
36	*Z Vulpeculae*	B	2.455	7.80	1.65	A	U	.749	.251	.314	.055	.872	.094	.048	4.7
					0.34		D	.749	.281	.296	.014	.922	.060	.051	3.3
37	*δ Librae*	W	2.327	4.83	1.10	A	U	.945	.324	.278	.104	....	.037	.058	13.0
					0.05:		D	.95	.386	.290	.098	....	.022	.051	11.0
38	*β Lyrae*	Sw	12.916	3.36	0.97	B8}p	D	.60	.271	.678	.499	.758	.0035	.0002	9.4
					0.45	B5}									
39	*RT Lacertae*	LzE	5.074	9.06	1.06	G5?	U	.602	.343	.343	.000	.949	.007	.007	1.5
					0.61		D	.602	.295	.295	.000	0.968	.011	.011	1.5
40	*SU Centauri*	L	5.354	8.73	0.87	F2	U	.926	.225	.203	.115	....	.021	.028	10.2
					0.06:		D	.934	.253	.213	.136	....	.014	.024	10.0
41	*RR Draconis*	Sh	2.831	9.98	2.96	A	U	.934	.099	.249	.136	....	.86	.054	90.0
		ms			[0.01]		D	.934	.131	.226	.076	....	.37	.072	42.0
42	*UZ Cygni*	W	31.304	10.29	1.88	A	U	.823	.070	.174	.049	....	.020	.0013	29.0
					[0.03]		D	.823	.084	.167	.000	....	.012	.0011	18.5
43	*VW Cygni*	G	8.431	10.32	1.94	A	U	.832	.106	.222	.036	....	.078	.009	22.0
					[0.04]		D	.832	.117	.217	(0)	....	0.059	0.009	17.0
44	*ε Aurigae*	Lu	9905.	3.26	0.75	F8p	U_1	.50	.030	.298	.249	....	3×10^{-6}	3×10^{-9}	100.0
							U_2	.50	.059	.170	(0)	....	3×10^{-7}	10^{-8}	8.0
							D_1	.50	.031	.307	.225	....	2×10^{-6}	2×10^{-9}	100.0
							D_2	.50	.069	.173	(0)	....	2×10^{-7}	10^{-8}	6.0
45	*RW Capricorni*	Sh	3.392	9.2	1.45	A	U	.737	.206	.237	.031	....	0.067	0.044	3.7
		ms			0.24		D	.788	.229	.229	.045	....	.049	.049	3.7
46	*RT Scuti*	Wh	0.512	9.65	0.71	F	U	.941	.435	.524	.442	0.800	.49	.28	23.0
					0.20:		D	.955	.498	.498	.452	0.880	.27	.27	21.0
47	*RS Cephei*	W	12.42	10.19	1.66	Ap	U	.783	.057	.229	.133	....	.23	.004	58.0
		ms			[0.02]		D	.783	.079	.197	.026	....	.089	.006	22.0
48	*SV Centauri*	L	1.661	8.80	0.86	A	U	.72	.323	.323	.122	....	.072	.072	2.6
					0.26		D	.771	.369	.314	.142	....	.049	0.079	4.7
49	*RZ Ophiuchi*	SeN	261.8	9.75	0.83	G8	U	.53	.037	.185	.112	....	.002	2×10^{-5}	28.0
		ms			[0.02]		D	0.53	0.046	0.154	0.047	....	0.001	3×10^{-5}	12.0

CATALOGUE OF THE ORBITS OF ECLIPSING BINARIES—*Continued*

No.	Star	Obs.	Period	Max.	Range	Sp.	Sol.	L_b	r_b	r_f	cos i	b/a	ρ_b	ρ_f	J_b/J_f
(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)	(12)	(13)	(14)	(15)	(16)
50	*SS Centauri*	L	2.479	8.73	1.55	B9	U	0.939	0.174	0.272	0.167	....	0.21	0.055	30.0
					(<0.05)		D	1.00	.213	.263	.146	....	.11	.060	∞
51	*SS Carinae*	L	6.602	12.29	0.66	*lf*	U_1	0.544	.113	.123	.010	....	.106	.083	1.0
					0.66		U_2	.500	.118	.118	.016	....	.094	.094	1.0
							D_2	.500	.115	.115	.016	....	.10	.10	1.0
52	*WW Cygni*	G	3.318	10.00	2.91	Ap	U	.931	.188	.265	.073	....	.091	.032	27.0
					[0.04]		D	.931	.226	.258	.016	....	.053	.035	14.0
53	*RR Velorum*	Ro	1.854	10.00	0.91	A	U	.691	.140	.197	.108	....	.71	.25	4.4
					0.15		D	0.767	0.166	0.195	0.120	....	0.42	0.26	4.5

STARS WITH LIGHT-CURVES DETERMINED BY NIJLAND

No.	Star	Obs.	Period	Max.	Range	Sp.	Sol.	L_b	r_b	r_f	cos i	b/a	ρ_b	ρ_f	J_b/J_f
54*	*RY Persei*	N	6.864	8.20	2.37	A2	U	0.887	0.144	0.252	0.081	....	0.048	0.009	24.0
		ms			[0.04]		D	.887	.179	.242	.000	....	.025	.010	14.0
55	*RW Geminorum*	N	2.865	9.80	2.14	A	U	.861	.217	.319	.004	....	.080	.025	14.0
		ms			[0.07]		D	.861	.248	.310	(0)	....	.054	.027	10.0
56	*Z Persei*	N	3.056	9.60	2.70	A	U	.917	.116	.232	(0)	....	.46	.057	44.0
		ms			[0.02]		D	0.917	.132	.231	(0)	....	.31	.058	34.0
57	*Y Camelopardalis*	N	3.306	9.75	2.02		U	1.00	.180	.243	.121	....	.106	.043	....
		ms			(0.00)		U	0.844	.171	.244	.073	....	.123	.043	11.0
					(0.09)		D	0.844	.207	.238	.030	....	.069	.045	7.0
58*	*RR Delphini*	N	4.599	10.50	1.20	A	U_1	1.00	.092	.341	.313	....	.40	.008	∞
		ms			(0.00)		U_2	0.669	.106	.234	.128	....	.27	.025	9.6
					(0.08)		D_2	.673	.136	.216	.087	....	.13	.032	5.2
59	*ST Persei*	N	2.648	9.80	2.08	A	U	.853	.169	.264	.083	....	.20	.052	14.0
		ms			[0.07]		D	.853	.206	.253	.000	....	.11	.058	8.8
60	*RV Persei*	N	1.974	10.75	2.20	A	U_1	.954	.291	.434	.208	....	.070	.021	45.0
		ms			(0.02)		U_2	.868	.290	.427	.137	....	.070	.022	14.0
					(0.07)		D_2	0.870	0.355	0.418	0.065	....	0.039	0.024	9.0

61	*SY Andromedae*.....	N	34.912	10.65	1.50	A?	U	0.749	0.036	0.119	(0)	....	0.120	0.0033	33.0
		ms			[0.02]		D	.749	.042	.120	(0)	....	0.075	.0032	24.0
62	*RW Ursae Majoris* ..	N	7.328	10.35	1.05	G?	U	.62	.025	.249	0.186	....	1.00	.008	41.0
		ms			[0.01]		D	.62	.071	.202	.112	....	0.35	.015	13.0
63	*TW Draconis*.......	N	2.806	7.30	1.60	B9	U	.771	.130	.371	.244	....	.39	.017	26.0
		ms			(0.03)		D	0.780	.180	.334	.177	....	.14	.023	12.0
64	*TT Lyrae*..........	N	5.244	9.45	2.20	A	U_1	1.00	.128	.284	.198	....	.118	.011	∞
		ms			(0.00)		U_2	0.868	.132	.254	.122	....	.106	.015	25.0
					(0.04)		D_2	.877	.152	.253	.116	....	.070	.015	20.0
65	*TT Andromedae*.....	N	2.765	11.30	1.30	A	U	.698	.158	.244	.084	....	.22	.060	5.5
		ms			[0.15]		D	.803	.177	.253	.141	....	.16	.055	8.4
66	*SY Cygni*..........	N	6.006	10.90	2.30	G5?	U	.88	.090	.237	(0)	....	.25	.014	51.0
		ms			[0.02]		D	.88	.100	.237	(0)	....	.19	.014	42.0
67	*RS Vulpeculae*......	N	4.477	7.35	0.68	A	U	.535	.272	.082	.030	....	.017	.61	0.10
		ms			[0.05]		D	.535	.252	.088	(0)	....	.021	.50	0.14
68	*TV Cassiopeiae*......	N	1.813	7.35	1.00	B9	U	.925	.248	.261	.155	....	.14	.12	14.0
		ms			(0.05)		D	.923	.272	.272	.176	....	.10	.10	12.0
69	3.1911 (*Cancri*).....	N	10.174	10.10	1.55	*tf*	U	.76	.048	.194	.105	....	.57	.009	51.0
		ms			[0.02]		D	.76	.057	.190	.096	....	.35	.010	35.0
70	*VV Cygni*..........	N	1.477	12.85	0.75	*tf*	U	.832	.211	.222	.149	....	.33	.28	5.5
		ms			(0.10)		D	.874	.251	.224	.161	....	.20	.27	5.5
71	*RV Lyrae*..........	N	3.599	11.60	1.90	A	U	.826	.089	.296	.191	....	.73	.020	53.0
		ms			[0.02]		D	0.826	0.126	0.258	0.107	....	0.26	0.031	20.0

GRADE III. STARS INSUFFICIENTLY OBSERVED

72	*RZ Draconis*........	W	0.551	9.97	0.80	Ap	U	0.90	0.34	0.44	0.330	0.815	0.82	0.39	15.0
					0.22		D	.96	.40	.40	.332	.886	.43	.43	22.0
73	*SZ Herculis*.........	Sh	0.818	9.5	1.48	*tf*	U	.74	.25	.33	.019	....	.62	.28	4.9
		ms			[0.18]		D	.74	.27	.32	.000	....	.54	.31	4.2
74	*SV Tauri*..........	E	2.167	9.37	0.72	A	U	.96	.27	.19	.000	....	.075	.21	12.0
					0.05:		D	0.95	0.30	0.19	(0)	....	0.051	0.20	7.5

CATALOGUE OF THE ORBITS OF ECLIPSING BINARIES—*Continued*

No.	Star	Obs.	Period	Max.	Range	Sp.	Sol.	L_b	r_b	r_f	cos *i*	*b/a*	ρ_b	ρ_f	J_b/J_f
(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)	(12)	(13)	(14)	(15)	(16)
75	*RX Cassiopeiae*	W	32.315	8.66	0.69	KO	U	0.57	0.27	0.27	0.136	0.809	0.0005	0.0005	1.3
					0.55		D	.57	.28	.28	.170	.880	.0004	.0004	1.3
76	*RZ Scuti*	BWy	15.194	7.47	1.38	B3	U	.88	.143	.298	.216	....	.010	.0011	29.0
					0.03:		D	.90	.157	.314	.238	....	.008	.0010	36.0
77	*Y Cygni*	W	2.996	6.95	0.60	A	U	.58	.167	.167	.070	....	.16	.16	1.4
		ms			0.40		D	.58	.166	.166	.088	....	.16	.16	1.4
78	*SX Cassiopeiae*......	Lz	36.572	8.68	1.00	G3	U	.53	.21	.32	.115	.846	.0008	.0002	2.7
					0.41		D	.66	.26	.32	.180	.905	.0003	.0002	2.9
79	*SY Centauri*........	L	6.631	9.88	0.87	A	U	.76	.15	.45	.39	....	.042	.002	28.0
					(0.02)		D	.79	.18	.45	.39	....	.026	.002	33.0
80	*SW Centauri*........	L	5.219	9.12	2.33	A	U	.88	.09	.23	(0)	....	.32	.021	47.0
					0.02		D	.88	.10	.23	(0)	....	.22	.021	36.0
81	*RS Scuti*...........	I	1.329	8.86	0.93	F	U	.50	.26	.26	.00	.848	.30	.30	1.0
					0.93		D	.50	.27	.27	.00	.905	.24	.24	1.0
82	*RZ Aurigae*.........	Pr	3.011	10.5	1.74	*tf*	U	.80	.21	.27	.05	....	.080	.036	6.7
					[0.13]		D	.80	.26	.27	.00	....	.044	.036	4.2
83	*RW Persei*..........	P	13.199	9.5	2.2	A	U	.87	.06	.16	(0)	....	.14	.009	41.0
					[0.02]		D	.87	.08	.16	(0)	....	.09	.009	30.0
84	*RR Puppis*.........	In	6.430	9.45	1.11	A	U	.64	.10	.24	(0)	....	.17	.012	10.0
					[0.07]		D	.64	.11	.24	(0)	....	.12	.013	8.0
85	*Y Leonis*...........	Le	1.686	9.4	2.75	A	U	.92	.16	.26	.10	....	.60	.13	31.0
					[0.03]		D	.92	.20	.25	.07	....	.31	.14	19.0
86	*SX Sagittarii*.......	P	2.077	8.58	0.82	A5	U	.53	.19	.44	(0)	....	.22	.018	6.1
					[0.10]		D	.53	.25	.40	(0)	....	.11	.23	2.3
87	*X Carinae*	Ro	1.083	7.9	0.8	A	U	0.52	0.50	0.50	0.10	0.878	0.06	0.06	1.1

that the mass of each system is equally divided between the two components. This assumption will in general give the density for the bright star too low, and for the faint companion too high. The densities are usually given to the second significant figure, though they are often entirely uncertain in the last place. In the final column is given the ratio of the surface intensity of the star that has a majority of the light, to the surface intensity of the other. This ratio is greater than unity except in rare instances where the star that has the most light has a lower intensity per unit area.

AUXILIARY TABLES

1. Eccentricity of orbit has been determined for the stars listed below. In some other cases the orbits are known to be practically circular, but in most systems the evidence is insufficient. When only $e \cos \omega$ has been found from the displacement of the secondary minimum, I have assumed for this table $\omega = (0°)$ or $(180°)$, which gives minimum eccentricity; the uncertainty of such a determination justifies giving only circular elements in the catalogue. Spectrographic data were available for Nos. 17, 23, and 37.

	Star	Eccent.	Long. of Periastron		Star	Eccent.	Long. of Periastron
1	*Z Drac*......	0.010	(0°)	25	*W Cruc*......	0.06	(180°)
2	*RT Pers*.....	.012	(0)	27	*RS Sag*......	.092	261.1
17	*u Herc*......	.053	66.9	37	*δ Libr*.......	.054	29.2
19	*ST Car*.....	.052	(0)	78	*SX Cass*.....	.043	(180)
23	*R Can. Maj*..	0.138	90	87	*X Carin*......	0.02	165

2. With the aid of spectrographic data it is possible to find for four systems the radius of the orbit, dimensions of the stars, and

Star			Masses		Maxima Radii		Densities		Distance of Centers
			m_b	m_f	r_b	r_f	ρ_b	ρ_f	
3	*β Aurig.*	Unif........	2.38	2.34	2.58	2.58	0.14	0.14	17.7
		Dark.......	2.40	2.36	2.81	2.81	0.11	0.11	17.7
17	*u Herc.*	Unif........	7.50	2.87	4.60	5.48	0.097	0.022	14.7
		Dark.......	7.66	2.93	4.56	5.35	0.095	0.022	14.8
30	*V Pupp.*	Unif........	18.7	18.7	8.23	7.57	0.051	0.065	12.5
		Dark.......	19.4	19.4	8.45	7.70	0.042	0.055	12.7
38	*β Lyrae*	Dark.......	1.42	14.2	16.2	40.6	0.0006	0.0004	59.9

actual masses and densities—all in terms of the sun. The masses in the system of *V Puppis* are assumed equal. The mass ratio for *β Lyrae* was taken as 10/1 (see note).

3. A "reflection" effect has been detected in a few accurately observed stars, and no doubt its occurrence would be found quite general if the precision of the observations was increased. The bright side of the companion (toward the primary) gives out the light $1-L_b$ (see ninth column of the catalogue); the light of the opposite side is less by 0.040 for *Z Draconis*, 0.022 for *RT Persei*, 0.044 for *β Persei*, 0.025 for *RZ Centauri*, and 0.03 for *Z Herculis*.

NOTES TO THE CATALOGUE AND TABLES

1. *Z Draconis.*—The accuracy of the light-curves of the first four stars greatly exceeds that of all other eclipsing binaries. Their orbits will be discussed *in extenso* in a paper soon to be published. The solutions U_1 for *RT Persei* and for *Z Draconis* are by Dugan; other solutions for *Z Draconis* and D for *β Aurigae* are by Russell; U for *β Aurigae* and U_1 for *Algol* are by Stebbins.

6. *U Pegasi.*—First solution by Roberts, assuming stars in contact, *M.N.*, **66**, 135, 1906. Solutions indeterminate over a small range.

8. *S Cancri, SW Cygni, U Cephei, W Delphini.* See *Astrophysical Journal*, **36**, 269, 1912.

13. *RX Herculis*, 15. *U Sagittae.*—Harvard classifies spectra as A; Frost mentions helium lines; see *Astrophysical Journal*, **22**, 214, 215, 1905.

23. *R Canis Majoris.*—These orbits are based on Wendell's observations of 1898–1899 which show the secondary minimum exactly halfway between successive primaries. Jordan's elements from Allegheny spectrograms give $e=0.138$, $\omega=196°$ in 1908. Hence the line of apsides must be in motion, but there are no data to estimate its rate of revolution. With this value of the eccentricity, and considering that primary eclipse occurred at periastron, solutions U_1 and D_1 are obtained. They represent the observations satisfactorily. For the purpose of illustration U_2, which assumes the primary at apastron and fails to fit the secondary minimum well, and U_3, which is the set of circular elements, are given.

24. *W Ursae Majoris.*—Observations by Müller, Kempf, and Baldwin; solutions by Russell; see *Astrophysical Journal*, **36**, 139, 1912.

25. *W Crucis.*—Uniform solution by Russell; see *Astrophysical Journal*, **36**, 146, 1912.

26. *RR Centauri.*—Uniform solution by Roberts, *M.N.*, **63**, 545, 1904.

31. *Y Piscium*, 41. *RR Draconis.*—See *Astrophysical Journal*, **37**, 155, 1913.

38. *β Lyrae.*—The orbits previously obtained by Stein, Myers, Roberts, and von Hepperger are not consistent with the statement of Curtiss in *Alleg. Bull.*, **2**, 115, 1911, that the star eclipsed at primary minimum has the stronger continuous spectrum. In a recent letter Curtiss estimates that the primary star of type B8 has 60 per cent of the light of the system. The primary eclipse must then necessarily be partial, with large faint star in front. I am able to find no possible "uniform" orbit, but the "darkened" solution represents the light-variations quite satisfactorily, and at the same time conforms to the first hypothetical system deduced by Curtiss from his extensive spectroscopic investigation. He finds that the brighter star has at most one-tenth the mass of the other.

39. *RT Lacertae.*—Uniform solution very unsatisfactory; probably definite evidence of darkening toward the limb. *Astrophysical Journal*, **36**, 401, 1912.

42. *UZ Cygni.*—I find that Wendell's photometric observations contradict Hartwig's visual estimates relative to the secondary minimum. *A.N.*, **165**, 121, 1904, *V.J.S.*, **39**, 254, 1904; **40**, 329, 1904.

44. *ε Aurigae*, 49. *RZ Ophiuchi.*—See recent discussion of orbits in *A.N.*, **194**, 225 (1913). Spectrum of *RZ Ophiuchi* is estimated G5 to K0.

47. *RS Cephei.*—I have determined new light-elements from Wendell's manuscript observations: Min. = J.D. 2417140.469, G.M.T. + $12^{d}4204$.E.

54–71. *Nijland's stars.*—Variables for which the series of observations have been completed by Professor Nijland are marked with asterisks.

72. *RZ Draconis.*—A complete study of this star is being made at Princeton.

73. *SZ Herculis.*—Comparison star probably variable.

77. *Y Cygni.*—Only circular elements are possible from existing data; according to Dunér the orbit is highly eccentric.

78. *SX Cassiopeiae.*—Spectrum G0 to G5.

85. *Y Leonis.*—Elements from rough light-curve; observed magnitudes not available.

CONCLUSIONS

Among the general results obtained from the present investigation the following points may be briefly mentioned. The complete statistical discussion will be published later.

1. The better the observations of an eclipsing binary are, the more satisfactory is the theoretical representation of the light-variations. Irregularities in the shape of light-curves disappear with increasing photometric accuracy. Halts and inflections in them have no objective existence, and the only apparently real peculiarities are occasional slight asymmetries and brightening

toward periastron (*Astrophysical Journal*, **36**, 278, 1912; **36**, 146, 1912).

2. The existence of darkening toward the limb of stellar disks is indicated in a large number of systems by the slightly better agreement of the "darkened" solution with the observed data, and its existence is actually demonstrated in a few cases. The degree of darkening, however, is as yet quite indeterminate.

3. In all but one of 28 first-grade stars, three of 25 second grade, and one of 16 of the third grade, there is a positive indication that the fainter star is self-luminous, and in no case is it necessary to assume one component completely black. In about two-thirds of the systems the difference in brightness of the components does not exceed two magnitudes, and no observed difference is greater than four magnitudes.

4. Regarding the relative sizes of the two components of an eclipsing system the following table shows that the conspicuous preponderance of systems in which the fainter star is the larger is entirely a matter of selection; and suggests, further, that there exist great numbers of eclipsing stars of small range in which the faint companion is smaller.

Range		Faint Star Large	Bright Star Large	Stars Nearly Equal
Greater than one magnitude	Unif.	47	2	2
	Dark.	44	4	3
Less than one magnitude	Unif.	12	10	13
	Dark.	9	12	14
Total	Unif.	59	12	15
	Dark.	53	16	17

5. Whenever the relative color-index of the components has been determined from the difference between the photographic and visual ranges at total eclipse, the large faint star has been found to be the redder. These stars are therefore presumably of "later" spectral type than their primaries, but columns (14) and (15) of the catalogue show that they are almost certainly less dense. See *Astrophysical Journal*, **37**, 155 ff., 1913, for more complete discussion.

6. The relation between the separation of the components of a close system and the gravitational elongation is shown in the following table where the ratio of the equatorial axes, b/a, for "uniform" and "darkened" solutions is compared with Darwin's theoretical value for homogeneous, incompressible fluid.[1] In forming the groups in order of separation of the stellar disks, I have excluded *X Carinae*, for which the observational data are not available.

Number Stars	Mean Separation $1-a_b-a_f$	Uniform b/a	Darkened b/a	Darwin b/a
5	0.501	0.971	0.983	0.944
5	.399	.900	.939	.902
5	.315	.847	.906	.857
4	.196	.809	.883	.772
4	0.106	0.700	0.788	0.692

7. In forming a table showing the distribution of densities relative to spectra, the "darkened" values have been used; the relative distribution would be altered but little if the "uniform" densities had been taken.

Density	B	A	F	G	K
>1.00	...	...	...	1	...
1.00 to 0.50	...	...	1	...	...
0.50 to 0.20	1	10	6	1	...
0.20 to 0.10	4	12	1	1	...
0.10 to 0.05	3	17	...	...	...
0.05 to 0.02	2	8	...	...	...
0.02 to 0.01	...	3	1	1	...
0.01 to 0.001	2	...	...	...	...
0.001 to 0.0001	...	...	...	2	1
<0.0001	...	...	1	1	...
Total	12	50	10	7	1

The first-type stars (spectra B and A) show a marked preference for an intermediate density, 75 per cent of them coming between the values 0.02 and 0.20, while out of the 18 second-type stars only two fall into that interval, and for one of them a small and permissible change of the elements would take it out of these limits.

[1] See *Astrophysical Journal*, **36**, 62, 1912.

The second-type stars fall apparently into two groups, of which one precedes and one follows the first-type stars in order of density. These two groups are obviously identical with the two classes of second-type stars of very greatly different luminosity discussed by Hertzsprung[1] and Russell,[2] and the facts collected here afford direct support of Russell's theory that the differences in brightness of the two groups are to be ascribed in the main to great differences in the mean density.[3]

PRINCETON UNIVERSITY OBSERVATORY
March 1913

[1] *Zeit. für wiss. Phot.*, **3**, 429; **5**, 86, 1907.

[2] *Astrophysical Journal*, **36**, 153, 1912.

[3] *Science*, N.S., **34**, 523, 1911; *Proc. Am. Phil. Soc.*, **51**, 569, 1912.

ORBIT OF THE SPECTROSCOPIC BINARY π^5 *ORIONIS*

By OLIVER J. LEE

The variable radial velocity of π^5 *Orionis* ($\alpha=4^h49^m$; $\delta=+2°17'$; mag. $=3.9$) was discovered and announced by Frost and Adams.[1] The spectrum of this star is classified as B 3 in the *Harvard Revised Photometry*. The lines are often faint and always diffuse and difficult to measure. No evidence of the spectrum of the second component has been found. The present discussion is based upon measures of 64 plates, seven of which were taken in 1902–1903 with the three-prism dispersion of the Bruce spectrograph, the other 57 plates were taken with one prism.

The following lines were used in obtaining the velocities:

Element	Wave-Length	Element	Wave-Length	Element	Wave-Length
H.........	3970.213	*He*........	4143.919	*Mg*........	4481.400
He.........	4009.417	*C*..........	4267.301	*Si*.........	4552.636
He.........	4026.342	*H*..........	4340.634	*Si*.........	4567.897
H.........	4101.900	*He*........	4388.100	*Si*.........	4574.791
Si.........	4116.400	*He*........	4437.718	*He*........	4713.252
He.........	4120.973	*He*........	4471.646	*H*.........	4861.527

The lines at λ 4143.919, λ 4340.634, λ 4388.100, and λ 4471.646 are usually best and they have been given most weight.

For the first seven plates given in the Table of Observations the measures of five are due to Adams, while the means of measures by Frost and Adams are given for B 475 and B 488. These early observations fall well along the velocity-curve, considering that three-prism dispersion is much too great for a spectrum of this type. They have been included in deriving the normal points. All the remaining measures are mine.

Since our observations of this star cover more than ten years, a precise determination of the period was possible from Bruce plates alone, and the value 3.70045 days was adopted as definitive. With this period and the resulting observational velocity-curve a preliminary set of elements was derived by the graphical method

[1] *Astrophysical Journal*, 17, 150, 1903.

TABLE OF OBSERVATIONS

Plate No.	Observer	G.M.T.	Phase	No. of Lines	Wt.	Velocity	Residual O.−C.
			Days			km	km
		1902					
A 332...	A	Mar. 4.608	1.23	3	2	+1	+5.7
B 469...	A	Dec. 17.712	0.69	5	4	+58	+10.7
B 475...	A	31.689	3.56	6	1	+71	−9.9
		1903					
B 480...	A	Jan. 1.743	0.92	4	2	+32	+7.4
A 384...	A	16.710	1.09	6	3	+7	−0.4
B 488...	A	21.562	2.24	4	2	−34	−12.5
A 390...	F	22.688	3.35	4	2	+73	+0.9
		1907					
I B 1276..	F	Dec. 6.635	2.39	6	5	−9	+1.8
1278..	Fox, L	6.772	2.53	6	4	−2	−3.9
1280..	L	6.836	2.59	8	4	+14	+6.8
1285..	L	11.582	3.64	7	3	+80	0.0
1293..	F, L	20.630	1.59	4	4	−30	−1.6
1295..	B	20.824	1.78	6	4	−34	−1.0
1296..	B	28.537	2.10	5	4	−28	+0.6
1298..	B	28.708	2.27	8	3	−33	−13.2
1300..	Fox	30.631	0.49	6	5	+58	−5.4
1303..	Fox	30.800	0.66	7	4	+51	+0.9
		1908					
1312..	L	Jan. 7.616	1.08	7	3	+14	+5.7
1314..	L	7.686	1.15	3	2	−11	−19.3
1326..	B	14.639	0.71	6	5	+47	+1.8
1329..	B	14.744	0.81	7	3	+29	−8.3
1351..	F, B	20.557	2.93	6	4	+26	−13.2
1355..	B	20.676	3.05	6	3	+46	−4.0
1357..	L	21.522	0.18	11	4	+70	−9.8
1360..	L	21.656	0.31	12	4	+72	−1.0
1744..	...	Sept. 18.956	1.09	6	2	+16	+8.6
1897..	L	Dec. 7.717	3.14	5	3	+51	−5.7
1904..	B	14.856	2.88	8	5	+36	+1.7
		1909					
1989..	F	Mar. 1.588	1.90	8	4	−36	−2.6
2160..	B	Oct. 25.828	3.31	9	3	+53	−16.9
2169..	L	29.876	3.67	9	4	+73	−9.5
2174..	B	Nov. 5.764	3.15	9	4	+52	−6.1
2190..	L	22.665	1.55	8	3	−37	−10.3
2208..	B	Dec. 17.624	0.60	5	3	+54	−1.0
2219..	F	22.697	1.97	9	3	−40	−7.3
2223..	L	22.861	2.13	6	2	−37	−10.0
		1910					
2231..	L	Jan. 3.547	2.72	10	3	+20	+1.7
2237..	L, B	3.780	2.95	10	3	+42	0.0
2248..	B	14.549	2.61	9	3	+12	+4.0
2255..	L	14.822	2.88	10	4	+29	−5.9
2261..	L	18.556	2.93	10	4	+26	−13.2
2276..	L	Feb. 7.524	0.69	6	3	+41	−6.3
2280..	L	14.589	0.35	6	3	+73	+0.9
		1912					
3100..	B	Sept. 30.961	1.33	8	4	−16	+2.9
3104..	L	Oct. 4.849	1.51	11	4	−19	−5.1
3105..	L	4.889	1.55	14	5	−19	−7.6

TABLE OF OBSERVATIONS—*Continued*

Plate No.	Observer	G.M.T.	Phase	No. of Lines	Wt.	Velocity	Residual O.−C.
		1912	Days			km	km
I B 3114..	L	14.900	0.47	14	4	+81	+15.7
3115..	L	14.956	0.53	12	5	+71	+10.7
3122..	M	25.793	0.26	8	2	+87	+10.6
3123..	M, L	25.949	0.32	5	2	+86	+11.9
3125..	L	25.901	0.37	9	4	+80	+ 9.0
3135..	M	Nov. 4.683	2.75	8	2	+15	− 5.9
3138..	L	4.847	2.91	11	4	+35	− 2.4
3142..	M	6.825	1.19	10	4	+10	+11.1
3144..	M	6.974	1.34	9	4	−10	+ 3.6
3148..	L	8.767	3.13	11	5	+64	+ 6.2
3149..	L, B	8.803	3.17	11	5	+65	+ 5.2
3151..	B	8.958	3.33	12	4	+82	+10.6
3155..	L	18.734	1.99	9	3	−26	+ 5.9
3158..	M	18.892	2.15	9	3	−16	+10.0
3163..	B	19.699	2.96	11	5	+34	− 8.9
3164..	B	19.792	3.05	11	4	+58	+ 7.9
3169..	B	22.712	2.27	12	4	−15	+ 4.5
3170..	B	22.765	2.32	11	4	−12	+ 2.2

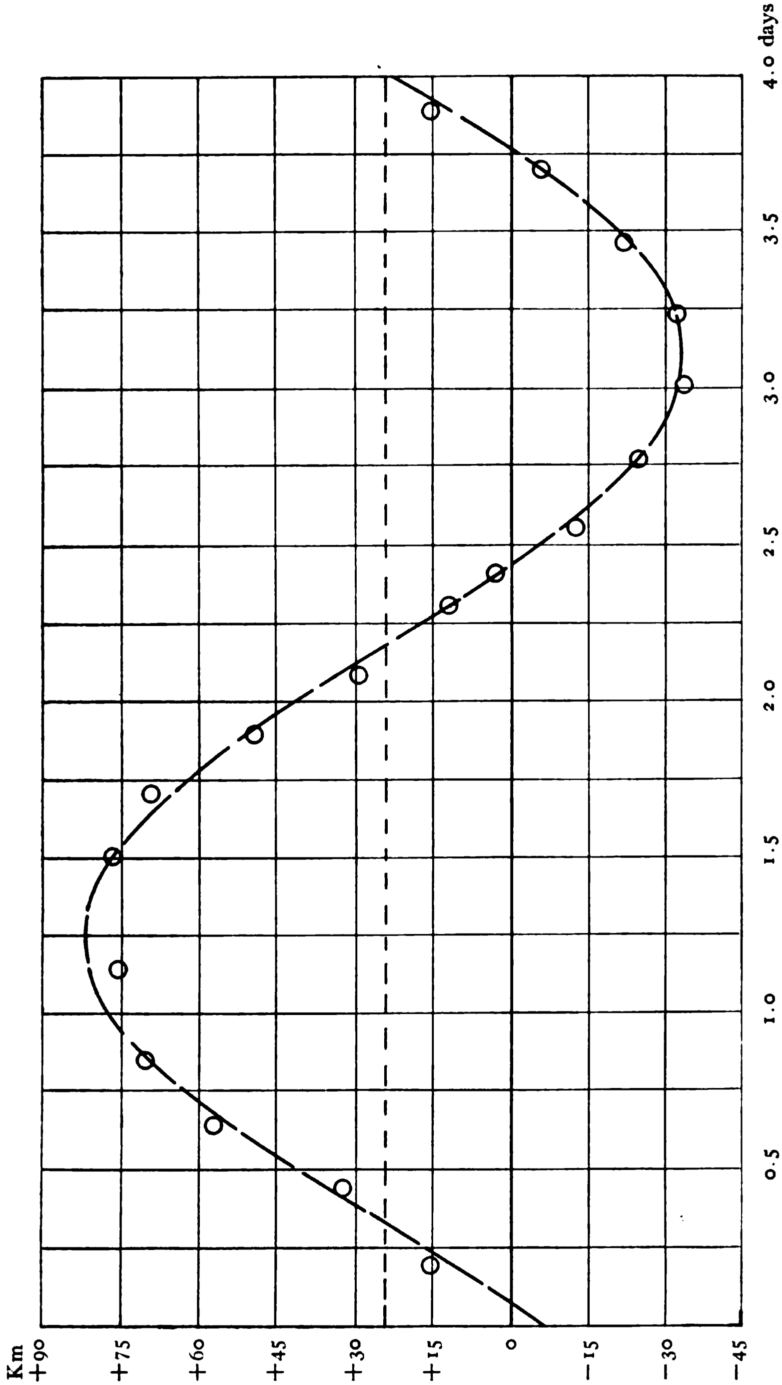
In column headed "Observer," A=Adams; B=Barrett; F=Frost; L=Lee; M=S. A. Mitchell. Mr. F. R. Sullivan assisted as usual in securing the plates.

TABLE OF NORMAL PLACES

No.	Phase	Limits of Phase	Velocity	Residual O.−C.	Wt.
	Days	d. to d.	km	km	
1..........	0.26	0.1 0.4	+76.5	0.0	0.6
2..........	0.46	0.4 0.6	+69.2	+3.9	0.5
3..........	0.64	0.6 0.7	+49.4	−1.7	0.6
4..........	0.83	0.7 0.9	+29.6	−3.9	0.2
5..........	1.06	1.1	+11.9	+0.8	0.3
6..........	1.16	1.1 1.2	+ 2.5	+0.8	0.3
7..........	1.30	1.3	−13.0	−2.8	0.3
8..........	1.52	1.5 1.6	−25.1	−0.3	0.5
9..........	1.76	1.8	−34.0	−1.0	0.1
10..........	1.98	1.9 2.1	−32.4	−0.1	0.5
11..........	2.21	2.1 2.3	−22.1	−1.1	0.6
12..........	2.45	2.4 2.5	− 5.9	+0.2	0.3
13..........	2.64	2.5 2.8	+15.2	+4.2	0.4
14..........	2.89	2.8 3.0	+32.4	−3.0	1.0
15..........	3.09	3.0 3.2	+57.3	+2.6	0.8
16..........	3.30	3.3	+70.3	+1.1	0.3
17..........	3.59	3.5 3.7	+75.4	−5.7	0.3

of Lehmann-Filhés.[1] This orbit was given at the Cleveland meeting of the American Association. Later it was concluded that this series of observations would justify the labor of making a least-

[1] *Astronomische Nachrichten*, 136, 17, 1894.



Velocity-curve of π^5 *Orionis*

squares solution of the orbit. Accordingly the observations were grouped into 17 normal places depending upon the phase, and the weights were assigned. Equations of condition were formed with five unknowns, viz., $\delta\gamma$, δK, δe, $\delta\omega$, and δT. The differential formulae of Lehmann-Filhés (*loc. cit.*) were employed for the last four, while $\delta\gamma$ was added and was given a coefficient unity. In the resulting normal equations the similarity in form of the coefficients in the equations from $\delta\omega$ and δT showed that these quantities and therefore the others would not be well determined by this set of observations. The large value of the correction $\delta\omega$ and the reduction of the eccentricity from 0.051 to 0.010 by this solution showed that with observations so necessarily inexact as those of this star the work of determining an elliptical orbit having an eccentricity of the order of 0.01 would be useless. Hence a circular orbit was assumed having the following elements:

$$
\begin{aligned}
P &= 3.70045 \text{ days} \\
K &= 57.04 \text{ km} \\
\gamma &= +24.49 \text{ km} \\
T &= \text{J.D. } 2{,}417{,}921.64
\end{aligned}
$$

T is an epoch of maximum positive velocity of the star. With these elements an ephemeris was computed and differential coefficients derived for the 17 normal places. For the reason given above no correction to the period was sought.

The resulting normal equations are:

$$
\begin{array}{rrrl}
+7.600x & +0.222y & -0.586z & =-1.730 \\
 & +3.196 & +0.072 & =+2.583 \\
 & & +4.401 & =-1.865
\end{array}
$$

$$
\begin{aligned}
x &= \delta\gamma \\
y &= \delta K \\
z &= K\mu\delta T
\end{aligned}
$$

These equations yield the following corrections:

$$
\begin{aligned}
\delta\gamma &= -0.289 \text{ km} \\
\delta K &= +0.839 \text{ km} \\
\delta T &= -0.005 \text{ day}
\end{aligned}
$$

The corrected elements are:

$$
\begin{array}{rll}
P = & 3.70045 \text{ days} & \pm 0.00002 \text{ day} \\
K = & 57.88 \text{ km} & \pm 1.07 \text{ km} \\
\gamma = & +24.20 \text{ km} & \pm 0.70 \text{ km} \\
T = & \text{J.D. } 2,417,921.64 & \pm 0.01 \text{ day} \\
a \sin i = & 2,945,000 \text{ km} &
\end{array}
$$

The phases given for the plates and for the normal places are referred to the time of maximum velocity of recession. The residuals given in the Table of Observations are obtained by scaling from the final velocity-curve. The probable error of a single plate is ± 5.36 km. The residuals given in the Table of Normal Places are the differences between the observed value and the corrected ephemeris.

In only one instance do the residuals for the normal places derived from the final ephemeris differ more than 0.5 km from those obtained by a direct substitution in the equations of condition. Hence, in this case, it does not seem necessary to make a second solution..

In the preliminary investigation, made to find a satisfactory set of elliptical elements, the *Tables for the True Anomaly in Elliptic Orbits*, which form No. 17, Vol. 2, of the "Publications of the Allegheny Observatory," were found to be very convenient.

YERKES OBSERVATORY
March 1913

THE VARIATION OF THE SUN

By C. G. Abbot, F. E. Fowle, and L. B. Aldrich[1]

In the year 1902 preliminary experiments were begun at Washington to determine the solar constant of radiation. About 700 determinations of it have now been obtained, depending on observations at altitudes ranging from sea-level to 4420 meters. As originally devised by Langley, we determine spectral energy intensities and atmospheric transmission coefficients for numerous wave-lengths between about 0.30 μ in the ultra-violet and 2.5 μ in the infra-red, by spectrobolometric observations at high and low sun. The indications of the spectrobolometer are reduced to the standard scale of calories per square centimeter per minute by means of the readings of the pyrheliometer.

At the time when the observations were begun in 1902 there was no satisfactory establishment of the standard scale of pyrheliometry, nor indeed any pyrheliometer which was invariable relatively to itself from year to year. We at first made use of a modification of Tyndall's mercury pyrheliometer. This was improved in 1906 as the copper disk pyrheliometer, which has been in use on Mount Wilson ever since, and which is described in Vol. 2 of the *Annals of the Astrophysical Observatory*. A still later improvement took place in 1910 with the introduction of the so-called "Silver-Disk Pyrheliometer" which has attained considerable favor, and which is now in use in numerous countries. Neither of these instruments is capable of yielding independently the standard scale of radiation, but they possess the valuable qualities of simplicity and of being constant from year to year. Beginning with the year 1903 and extending until the end of the year 1912 we have repeatedly devised and experimented with instruments to fix the standard scale of radiation. Three of these instruments (called Water-Flow Pyrheliometers Nos. 2 and 3, and Water-Stir Pyrheliometer No. 4) have been tested with satisfactory results which are stated in a publica-

[1] Published by permission of the Secretary of the Smithsonian Institution.

tion by two of us.[1] We are now satisfied that the measurements made since 1903 can be reduced to the standard scale of radiation to within 1 per cent.

Measurements of the solar constant of radiation were begun at Washington, practically at sea-level, and were continued when favorable opportunities presented themselves from October 1902 until May 1907. Measurements were begun on Mount Wilson in California (elevation 1730 meters) in 1905, and have been continued with the exception of 1907 during about 6 months in the year in each of the succeeding years. Expeditions to Mount Whitney in California, altitude 4420 meters, were made in 1908, 1909, 1910. Expeditions to Bassour, Algeria, altitude 1160 meters, were conducted in the autumn of 1911 and the summer of 1912. In all 696 complete determinations of the solar constant of radiation have been made, and still others are unreduced. The differences found between the results at different elevations are very small, and seem attributable rather to experimental error or slight atmospheric irregularities than to any difference of elevation. The mean of all these 696 determinations made principally between the years 1905 and 1912 is 1,932 calories per square centimeter per minute.

Subject to the possibility that there may exist ultra-violet rays of appreciable intensity beyond the wave-length 0.29 μ, which are cut off by the absorption of ozone from reaching the earth's surface, we believe that this value represents the intensity of the radiation of the sun as it would be found in space at the earth's mean solar distance for the epoch 1905 to 1912.

In the year 1903 we found indications that the radiation of the sun is not constant from day to day.[2] It has been a main object of the work to ascertain if these apparent variations of the sun are really solar, or are due to some accidental or atmospheric influences not fully eliminated. As early as the year 1910 it had been shown that practically equal solar-constant values were obtained on good days at sea-level, at 1730 and at 4420 meters elevation, and it had been shown that the apparent fluctuations of the solar radiation

[1] See "Smithsonian Pyrheliometry Revised," *Smithsonian Miscellaneous Collections*, **60**, No. 18, 1913.

[2] See *Astrophysical Journal*, **19**, 305, 1903.

found on Mount Wilson from day to day marched by regular steps from high to low values and return, not fluctuating wildly as they would have done had they been due to experimental error. Accordingly it seemed from the first consideration (namely, that altitude did not appear to affect the results) that the atmosphere was not the cause of the fluctuation; and from the second consideration (namely, that the values marched step by step from high to low or vice versa) that it was not an accidental fluctuation. Hence, the most probable conclusion was either that the radiation of the sun is actually variable, or that some meteoric or other matter, by interposition between the earth and the sun, alters the quantity of the radiation received at the earth from day to day. The fluctuations appeared to be of irregular magnitude and period, often ranging through 5 per cent or more, in an interval of 7 or 10 days.

However probable the result just stated might appear, it could not be fully verified without carrying out the observation simultaneously at two stations widely separated on the earth's surface, so that no local atmospheric influences could be supposed to affect both stations at once. This extension of the work was made possible by the Algerian expeditions of 1911 and 1912. Solar-constant determinations were made nearly simultaneously at Mount Wilson, California, and Bassour, Algeria, separated by about one-third of the circumference of the earth. A difference of time of about 8 hours generally occurred between the observations, but inasmuch as the apparent fluctuations of the sun seldom reach 1 per cent in a day, this difference of 8 hours seems not much prejudicial to the comparison.

We were somewhat unlucky in our expeditions. In 1911 a box containing the bolometer and other necessary parts was delayed one month in reaching Algeria, so that a long period of good weather in August was lost. Also the months of September, October, and November 1911 proved less favorable than usual at Mount Wilson and less favorable than had been hoped at Bassour. Thus the number of days in 1911 in which good observations were secured in both places was rather small. In the year 1912, although the sky was generally cloudless, the eruption of the volcano of Mount Katmai in Alaska of June 6 and 7 so filled the sky with haze,

both at Mount Wilson and at Bassour, that a great many days of July and August were rendered unsuitable for comparison between the two stations. Thus it occurred that of 75 days in which observations were secured at both stations in the years 1911 and 1912, only 48 were found good enough for satisfactory comparisons of the solar constant values obtained.

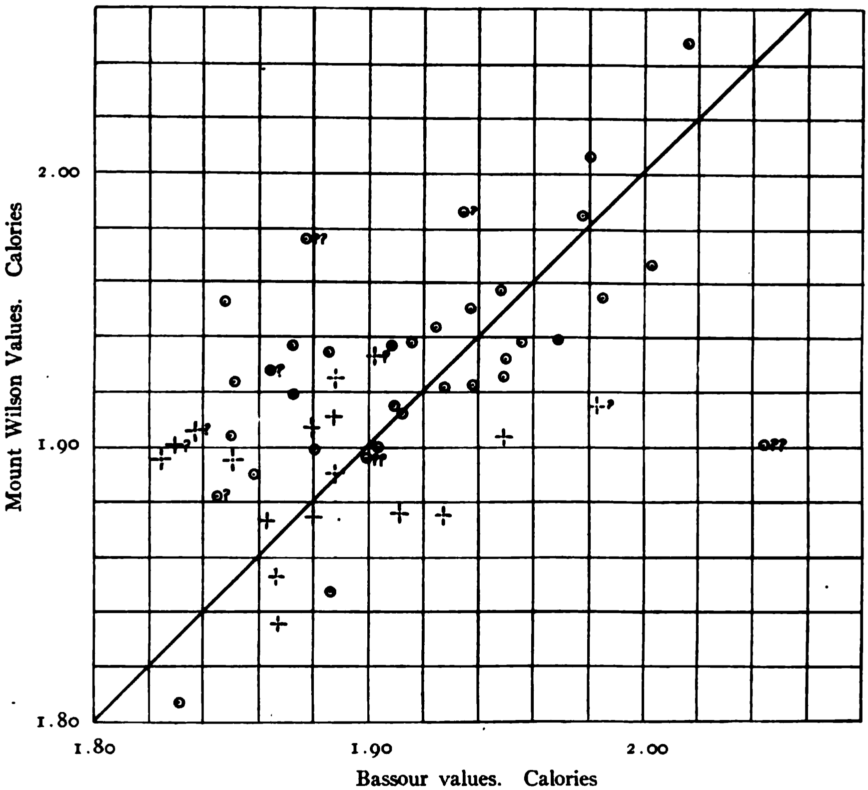


FIG. 1.—Comparison of Bassour and Mount Wilson values of the solar constant

For the purpose in view, namely, to show whether the apparent fluctuation of solar radiation is due to something outside the earth, it is immaterial whether the days of observation are consecutive or not. It is only required to know whether if high values are found at Bassour, high values will occur on the same day at Mount Wilson, and if low values are found at Bassour, low values will be found on

Mount Wilson. It matters not whether the days in question be found in one year or another, provided that they be numerous enough to exclude the probability that an agreement, if obtained, is owing wholly to chance.

The accompanying illustration gives the results of all the days found suitable for comparison between Bassour and Mount Wilson. Ordinates are solar constant values as obtained at Mount Wilson, abscissae are solar constant values as obtained at Bassour. Circles represent the results of days of the year 1912, and crosses represent the results of days of the year 1911. If the solar radiation had varied, and all determinations of it had been free from error, the points must all have lain upon the straight line inclined at 45 degrees to the axis. As it is impossible that results shall be entirely free from error, we must expect that the points representing individual days will be well represented by the 45-degree line if the sun is variable, but will fall uniformly distributed about one point on that line if the sun's radiation is constant. There is no difficulty in deciding that the line and not some single point of the line best represents the results here given.

The variation of the sun shown between the extreme observations amounts to 11 per cent and many observations unite in showing a variation of 7 per cent. The average deviation of the separate determinations at Bassour from those of the same days at Mount Wilson is 1.6 per cent.

Hence the average deviation of a single day of solar-constant measurement at one station will be $\left(\frac{1.6}{\sqrt{2}}=\right)$ 1.1 per cent, and the probable error of a single solar-constant measurement at one station will be 0.9 per cent. Had the condition of the sky in 1912 been free from the haze which prevailed owing to the volcanic eruption of Mount Katmai, we believe the probable error of the separate determinations of 1912 would have scarcely reached 0.5 per cent.

It will be seen that the measurements of 1912 are on the average above those of 1911, at both stations. The difference 1912–1911 is 0.04 calories per square centimeter per minute. This in itself may be regarded as an indication of the variation of the sun depending

upon nearly 20 days of observation in 1911 and about 30 days of observation of 1912.

In further study of the variation of the sun we have compared the mean solar-constant values obtained on Mount Wilson for the different months of the years 1905 to 1912 with the monthly values of the sun-spot numbers as published by Wolfer. We find a fluctuation of solar radiation in the sense that when the sun-spot numbers are high the solar radiation is high and vice versa.

It is also indicated that when the solar radiation is increased the intensity of the violet and ultra-violet rays of the solar spectrum (as it would be found outside the atmosphere) is increased with respect to the intensity of the red and infra-red.

Again it seems to be indicated that when the solar radiation is high the contrast between the brightness of the center and edge of the solar disk is greater than normal.

These and other results of this long investigation are published with details in Vol. 3 of the *Annals of the Astrophysical Observatory of the Smithsonian Institution*, now in press and expected to appear about July 1, 1913. The most important conclusions are as follows:

1. The mean value of the solar constant of radiation for the epoch 1905–1912 is 1.932 calories per square centimeter per minute.

2. An increase of 0.07 calories per square centimeter per minute in the "solar constant" accompanies an increase of 100 sun-spot numbers.

3. An irregular variation frequently ranging over 0.07 calories per square centimeter per minute within an interval of 10 days is established by numerous nearly simultaneous measurements at Mount Wilson, California, and Bassour, Algeria.

4. Indications of two wholly independent kinds incline us to think that these variations of solar radiation are caused within the sun, and not by interposing meteoric or other matter.

SMITHSONIAN ASTROPHYSICAL OBSERVATORY
WASHINGTON

THE USE OF THE PHOTO-ELECTRIC CELL IN STELLAR PHOTOMETRY

PRELIMINARY NOTE

By W. F. SCHULZ

The great sensitiveness of the photo-electric cell has been shown experimentally by Elster and Geitel,[1] by Nichols and Merritt,[2] and by J. G. Kemp.[3] From the results of these investigations it seemed that such a cell might be used to measure the light from fixed stars, and its variation. The following is an account of some successful preliminary experiments in an attempt to make such measurements.

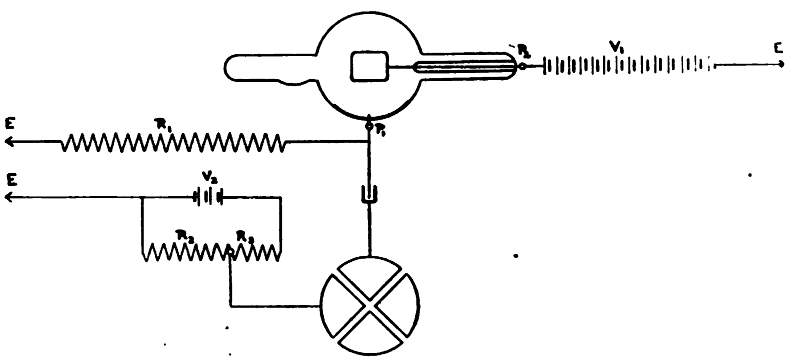


Diagram of apparatus

Several cells of the form shown in the accompanying diagram were prepared in the following way. The anode was a platinum wire about 0.5 mm in diameter, bent into a rectangular loop about $1 \times 1\frac{1}{2}$ cm on the side, the terminal passing through a glass sleeve 3 or 4 cm long. On the wall of the tube facing the plane of this loop was a layer of potassium which formed the cathode. In order to have good contact at the cathode a layer of silver was deposited on and around the platinum terminal on the inside of the bulb. The

[1] *Physikalische Zeitschrift*, **13**, 468, 1912.

[2] *Physical Review*, **34**, 476, 1912.

[3] *Ibid.* (2), **1**, 274, 1913.

bulb proper was about 5 cm in diameter. Potassium was distilled from a similar bulb into a second one, then poured into a pocket in the tube just outside of the bulb of the photo-electric cell and finally distilled upon the silver surface surrounding the cathode terminal.

A little hydrogen gas was then introduced by heating a strip of palladium contained in a side tube. A potential-difference of 560 volts D.C. was applied to the electrodes P_1 and P_2, P_1 being negative, with a lamp resistance of 3000 ohms in series with the cell. When the circuit was closed for a few seconds the bright metallic colors of the hydrogen compound appeared at once on the potassium. There was a uniform soft glow over the entire surface of the metal, the rest of the bulb being non-luminous. It was found necessary to use a rather high potential-difference with a resistance. When a potential-difference of 300 volts with little or no resistance was applied, the discharge took the form of an arc rather than that of a glow, and the current rose rapidly, in one case even melting the electrode.

The circuit was broken when the surface of the potassium had assumed a brilliant violet-blue color and the hydrogen was carefully pumped out and was replaced by a small quantity of helium. All traces of oxygen were removed from the helium by passing it through a tube in which potassium was evaporated, before introducing it into the cell. The photo-electric cell was next connected in series with a sensitive galvanometer and the lamp resistance, and a potential-difference of 300 volts was applied. The light from a small gas flame was allowed to fall on the metal of the cell, and the pressure in the latter was varied by small steps until the galvanometer deflection was a maximum. The tube was then sealed off and proved to be constant for a period of several months.

For measuring very small intensities of light two different methods were used. In the colder winter months, especially in the open observatory, the temperature of the cell was so low that the natural leak through the dark cell was negligible, and the photo-electric current was measured directly by the rate of deflection of a quadrant electrometer. Toward the spring, however, when the temperature rose, the natural leak through the cell increased rapidly

with the temperature, and it was found necessary to compensate this current by means of an independent circuit as shown in the diagram. The anode of the cell was connected to a storage battery of 160 cells, the negative terminal of which was earthed. The cathode was earthed through a high resistance R_1 and connected through a discharge key to one pair of quadrants of a Dolezalek electrometer. In the compensating circuit a battery of 3 cells sent current through a variable resistance R_2R_3 of 20,000 ohms, and the negative terminal was earthed. The other pair of quadrants was connected to R_2R_3 by means of a traveling plug. By this arrangement the "dark current" could be completely neutralized. V_1 was varied from 150 to 320 volts. This was not quite the upper limit at which the cell could be used, but 350 volts was too large, and the photo-electric current reached a value beyond that of saturation. R_1 was a very high resistance of xylol with just a trace of pure alcohol. The sensitiveness of the electrometer was such that a potential difference of 20 volts on the needle and 1.4 volts between the quadrants produced a deflection of 120 mm at a scale-distance of 2 meters. The deflections were very steady. The cell was tested by the light from a small incandescent lamp, which was cut down by passing it through two large crossed Nicol prisms. The cell was mounted in a light-tight box, carefully blackened inside, and closed by means of a shutter. A long closed tube was screwed into the opening of the box, and the lamp placed in this at 1.5 meter distance from the cell. The Nicols were inserted between lamp and cell, with a device for measuring and varying the angle between them. The candle-power of the lamp measured on a two-meter photometer with Lummer-Brodhun screen was approximately 0.003 at 6 volts. The deflections of the electrometer were easily read even when the planes of polarization made an angle of 85° with each other. The intensity of the light which passed through an opening of 1 sq. cm area at the cell was therefore $0.003 \times \cos^2 85/1.5^2 = 0.000010$ candle meters.

It has been shown by Ångström that the energy flowing from an amyl acetate lamp is approximately 10^{-8} gram calories per square cm at a distance of 1 meter. Assuming the Hefner unit and the

candle-power to be equal and the distribution of energy to be the same in both lamps, we find that the quantity of energy incident on the cell is approximately 0.000010×10^{-8} gram calories or 4.19×10^{-6} ergs. This produces a deflection of the electrometer which is easily read. So far the light from two stars has been measured by means of this cell; in December 1912, that of *Capella* and in April 1913, that of *Arcturus*. The cell in its light-tight box was mounted on the 12-inch equatorial at the observatory of the University of Illinois, and placed in such a position beyond the focal plane of the objective that the circle of illumination on the sensitive surface of the cell had an area of about 1 sq. cm.

On the cold December nights the natural leak through the cell was almost zero, and the photo-electric current was measured by the rate of the electrometer deflection. With 40 volts on the needle and 160 volts on the cell, the rate of deflection at a scale-distance of 2 meters was 20 mm in 30 seconds. With 200 volts on the cell, the rate was 18 mm in 20 seconds. These deflections were repeated without difficulty.

In April 1913, another set of readings was taken with the light from *Arcturus*. This time the dark current had to be compensated. With 60 volts on the needle and 250 on the cell, the deflection due to the photo-electric current alone was 22 mm. This was reduced to zero each time by varying the resistance R_3. With 60 volts on the needle and 300 on the cell, the deflection when the cell was exposed to the light of *Arcturus* was 48 mm; with 60 volts on the needle and 325 on the cell the deflection was 190 mm; and with 80 volts on the needle and 325 on the cell the deflection was 248 mm. The sensitiveness of both cell and electrometer can be increased.

These measurements seem to show that it is possible to use the photo-electric cell for astrophysical investigations. The present research is being continued along various lines. It is planned to compare the sensitiveness of the photo-electric cell with that of the selenium cell, and to study the influence of temperature upon the "dark current," the effect of the wave-length of the incident light upon the lower limit of sensitiveness, and the use of various alkali metals for the sensitive layer.

These measurements were made at the suggestion of my friend Dr. Jakob Kunz, to whom I am deeply indebted for the benefit of his invaluable experience in making the cells and for assistance in conducting the experiments.

University of Illinois
May 19, 1913

Minor Contributions and Notes

ARE DIFFRACTION PHENOMENA POSSIBLE AT SOLAR ECLIPSES?

At the beginning and at the end of solar eclipses, moving light and dark bands become visible on the ground, the so-called "flying shadows." Among the possible explanations of their appearance, an attempt to represent them as diffraction phenomena is worth considering, since not only the magnitudes but also the distances of the objects are considered in such an explanation.

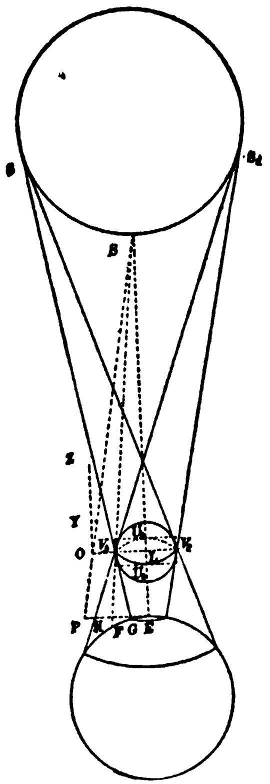


FIG. 1

To make a test of this form of explanation, I have used the diagram in Fig. 1. S represents a luminous point of the sun's surface, L the center of the moon, E one of the observed points on the earth's surface located on the line SL. We take a system of three rectangular axes X, Y, Z, of which the XY plane and X axis pass through L perpendicular to the line SE. The moon will then appear as a dark flat screen in the XY plane. Instead of this round screen, we may substitute the square screen $V_1V_2U_1U_2$ circumscribed about it, with sides parallel to the axes. On account of the symmetry, the phenomenon need only be studied in the XZ plane along the line EP which is perpendicular to SE. For a particular point P of this line the origin of coordinates, O will be taken as the intersection of PS with the X axis.

By Fresnel's theory of diffraction the intensity I in P is given by

$$I = A_1^2(C^2+S^2)$$

where $A_1 = \dfrac{A \cos \phi}{\lambda\rho_0\rho_1}$, A = amplitude in S, $\phi = ZOS$, $\rho_0 = OP$, $\rho_1 = OS$, λ = wave-length. Fresnel's integrals C and S are to be taken over the entire free part of the XY plane

$$C = f\left\{\left[\int_{-\infty,\, v_2}^{v_1,\, +\infty} \cos\frac{\pi}{2}v^2dv \int_{-\infty}^{+\infty} \cos\frac{\pi}{2}u^2du - \int_{-\infty,\, v_2}^{v_1,\, +\infty} \sin\frac{\pi}{2}v^2dv \int_{-\infty}^{+\infty} \sin\frac{\pi}{2}u^2du\right]\right.$$

$$\left. + \left[\int_{v_1}^{v_2} \cos\frac{\pi}{2}v^2dv \int_{-\infty,\, +u}^{-u,\, +\infty} \cos\frac{\pi}{2}u^2du - \int_{v_1}^{v_2} \sin\frac{\pi}{2}v^2dv \int_{-\infty,\, +u}^{-u,\, +\infty} \sin\frac{\pi}{2}u^2du\right]\right\},$$

$$S = f\left\{\left[\int_{-\infty,\, v_2}^{v_1,\, +\infty} \sin\frac{\pi}{2}v^2dv \int_{-\infty}^{+\infty} \cos\frac{\pi}{2}u^2du + \int_{-\infty,\, v_2}^{v_1,\, +\infty} \cos\frac{\pi}{2}v^2dv \int_{-\infty}^{+\infty} \sin\frac{\pi}{2}u^2du\right]\right.$$

$$\left. + \left[\int_{v_1}^{v_2} \sin\frac{\pi}{2}v^2dv \int_{-\infty,\, +u}^{-u,\, +\infty} \cos\frac{\pi}{2}u^2du + \int_{v_1}^{v_2} \cos\frac{\pi}{2}v^2dv \int_{-\infty,\, +u}^{-u,\, +\infty} \sin\frac{\pi}{2}u^2du\right]\right\},$$

where $f = \dfrac{\lambda\rho_0\rho_1}{2(\rho_0+\rho_1)\cos\phi}$, $v = x \cos\phi \sqrt{\dfrac{2(\rho_0+\rho_1)}{\lambda\rho\cdot\rho_1}}$, $u = y\sqrt{\dfrac{2(\rho\cdot+\rho_1)}{\lambda\rho\cdot\rho_1}}$,

$$x_1 = OV_1,\ x_2 = OV_2,\ y = LU_1 = LU_2.$$

Now the wave-length of light is $\lambda = 5.10^{-10}$ km, the radius of the moon $y = 1741$ km. When $\cos\phi = 1$, the distance from sun to moon $\rho_1 = a = 148{,}642{,}930$ km, the distance from the moon to the earth, $\rho_0 = b = 350{,}703$ km; thus we have $u = 186{,}152$. With arguments as big as the preceding ones we have

$$\int_{-u}^{+u} = \int_{-\infty}^{+\infty} = 1 \text{ and therefore} \int_{-\infty,\, +u}^{-u,\, +\infty} = \int_{-\infty}^{+\infty} - \int_{-u}^{+u} = 0.$$

Since we need investigate the diffraction only for points P for which the origin of co-ordinates O is close to the limit of the moon, we have

$$\int_{v_2}^{+\infty}=\int_{0}^{+\infty}-\int_{0}^{v_2}=0.$$

The intensity at P is then

$$I=\frac{I_0}{2}\left[\left(\int_{-\infty}^{v_1}\cos\frac{\pi}{2}v^2dv\right)^2+\left(\int_{-\infty}^{v_1}\sin\frac{\pi}{2}v^2dv\right)^2\right]\cdot$$

where $I_0=\frac{A^2}{(a+b)^2}$ represents the intensity at P without the screen. The simplifications which present themselves here mean physically that we are concerned only with diffraction phenomena at the limb of the moon. The geometric interpretation of the expression for I shows that $I=\frac{I_0}{2}\Big(-\infty, v_1\Big)^2$, i.e., proportional to the square of distance between the asymptotic point $-\infty$ and the point v_1, of Cornu's double spiral. If we take the point P as E and therefore O as L, then $v_1=-186{,}152$

$$(-\infty, -186{,}152)^2=0 \text{ and } I=0.$$

This means that there is darkness in the central band, although with a screen of smaller size, there would always be light in the axis of the geometrical shadow. If the point P is shifted from E to F, i.e., O from L to V_1, the intensity will increase continually and at F, on the edge of the geometric shadow of the point P we have

$$I=\frac{I_0}{2}(-\infty, 0)^2=\frac{I_0}{4}.$$

Shifting the point P outside of the geometrical shadow, maxima and minima will occur, maxima for $v_1=\sqrt{3/2+4h}$, and minima for $v_1=\sqrt{7/2+4h}$, $(h=0, 1, 2, \ldots)$.

If, instead of $OV_1=x_1$ the length $PF=d$ is introduced from the proportion $\frac{x_1}{d}=\frac{a}{a+b}$ we have

$$v_1=x_1\sqrt{\frac{2(a+b)}{\lambda ab}}=d\sqrt{\frac{2a}{\lambda b(a+b)}}\,.$$

Thus maxima and minima will occur at the following distances from the edge of the geometrical shadow of the point S.

$$\text{Maxima}: d=\sqrt{\frac{(3+8h)\lambda b(a+b)}{4a}} \qquad \text{Minima}: d=\sqrt{\frac{(7+8h)\lambda b(a+b)}{4a}}$$

With the numerical values which we have adopted, the first maximum will be at a distance $FP=d=11.5$ m; the next minimum at $FP=d=17.5$ m. The intensity of light at the first maximum is $I=1.34$; of the next minimum $I=0.78$, when $I_0=1$ is the free intensity from the point S of the sun. So far only one point of the sun has been considered. With a finite extension of the source of light, the individual diffraction patterns will be shifted with respect to each other; the resulting effect will be the superposition of the individual patterns in such a way that for a shift greater than the diffraction, all maxima and minima will have faded out. In our case, the shifts for points S_1 and S_2 in comparison with S is equal to $FG=FH=\frac{R\cdot b}{a}=1461$ km where $R=695740$ km.

Thus diffraction phenomena are excluded in the case of eclipses of the sun on account of the relative magnitudes of the quantities involved. In the umbra from E to F the intensity increases continuously and in the penumbra from F to H proportionally to the apparent part of the surface of the sun which is visible. Outside of the penumbra beyond H, where the bands originated by S_2 are not reached by the bands due to the preceding points, diffraction bands would be possible. They would be colored and in position parallel to the limits of the penumbra, violet on the inside, red on the outside, at distances as given above, but the full light of the sun would make them completely invisible.

Since beyond F the first maximum for $\lambda = 3.8 \times 10^{-10}$ km will appear at $d = 10.2$ m and for $\lambda = 7.6 \times 10^{-10}$ km at $d = 14.2$ m, the bands will be colored. By the superposition of the diffraction patterns of neighboring points of the sun, white light will result first at $d = 14.2$ m, while from $d = 10.2$ to $d = 14.2$, the light starting with blue will pass through mixed colors finally into white. The inner edge of the umbra should thus show a bluish lining.

The relative size of the quantities here encountered will also appear in other systems, e.g., eclipses of the sun in Jupiter's system. Here, too, the shadows of the satellites will project themselves without diffraction on the surface of Jupiter.

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THE MELTING-POINT OF MOLYBDENUM

In connection with the work discussed in an earlier article[1] a direct determination has been made of the melting-point of molybdenum by the V-method,[2] using pure ductile material kindly furnished by the General Electric Co. The strips were electrically heated *in vacuo*, and were cut slightly tapering from each end to the middle as viewed from the side, in order to predetermine the region of melting. Observations in the V and on the side with calibrated optical pyrometers gave the following (uncorrected) values for the true and black-body melting temperatures:

	True Temperature	Black-Body Temperature ($\lambda = 0.658\ \mu$)	Weights
1	2495° C.	2197° C.	2
2	2494	2215	6
3	2485	....	1
4	2512	2221	10
5	2506	2212	5
6	2496	2197	2
7	2485	2197	1
8	2512	2199	For true 6; For black-body 2
Weighted means	2504° C. ± 8°	2212° C.	

[1] *Astrophysical Journal*, **37**, 380, 1913.

[2] *Ibid.*, **33**, 91, 1911.

The correction for the absorption of the glass window is 30°.6 for 2500° and 24°.5 for 2212°, which makes for the true temperature of the melting-point of molybdenum **2535° C.**, and 2237° C. for the black-body melting-point, for $\lambda = 0.658\ \mu$.

These temperatures are on the basis of $c_2 = 14{,}500$ and the palladium melting-point at 1549° C. The weights were determined by the working conditions. In all cases, though sublimation is rapid in a vacuum, the ends of the filaments were evidently melted, and up to the time of melting no particular non-uniformity of temperature developed in the strips.

For comparison, this result is combined in the following table with others quoted from Pirani and Meyer:[1]

MELTING-POINTS OF MOLYBDENUM. DEGREES C.

Waidner and Burgess	v. Wartenberg	Ruff and Goecke	v. Pirani and Meyer	M. and F.
2500(?)	2521	2123	2393	2535

The figure quoted from Waidner and Burgess[2] is apparently only an estimate, that of v. Wartenberg is based on only two rather discordant (2440°, 2530° C.) observations in a vacuum tungsten tube furnace, and is merely given as " >2500," which, moreover, must be raised 20° for comparison with ours, because based on 1745° C. for the platinum melting-point. Pirani and Meyer's value is computed from the mean of two concordant observations of the black-body melting-point, assuming a constant value (0.51) for A_λ. If this value for the melting-point is to be compared with ours, it must also be increased about 15°, as they also used 1745° C. as the melting-point of platinum. Making this correction, and computing S from their published value of T, it follows that their observation of the black-body melting temperature must have agreed very closely with ours. We have not had access to the original paper of Ruff and Goecke. The greatest outstanding uncertainty, which we intend to study further, is undoubtedly as

[1] *Verh. der deutschen phys. Ges.*, **14**, No. 8, 1912.

[2] Burgess, *Measurement of High Temperatures* (1912), p. 492.

to whether the melting-point *in vacuo* is, because of rapid sublimation, lower than that in some neutral gas at atmospheric pressure. Aside from this possibility, our experience with molybdenum indicates that it is well adapted to furnish a standard high-temperature reference point.

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February 1913

NOTE ON THE TRANSMISSION OF THE ATMOSPHERE FOR EARTH RADIATION

In connection with the problem concerning the effective radiation from the earth's surface, it is of interest to regard the question of the transmission of the atmosphere for the earth radiation.

Very[1] has claimed a value of 40 per cent for the transmissive power of the atmosphere.

Abbot and Fowle,[2] on the other hand, are of the opinion that the atmosphere transmits only about one-tenth of the radiation from the liquid and solid surface of the earth, a conclusion that they found upon the measurement of Rubens and Aschkinass on the absorption of the water-vapor.

Without going into details regarding these considerations, we may here look for the conclusion that can be drawn from the direct measurements of the radiation to space.

The earth radiates for the wave-lengths with which we here are dealing almost as a black body, and should, if no atmospheric radiation existed, radiate to space $0.490 \frac{\text{cal.}}{\text{cm}^2 \text{ min.}}$, the temperature assumed to be 283° absolute.

The observed mean radiation (the effective radiation) is only about 0.15 (probably somewhat less, taking in regard the saturated water-vapor over the water surfaces), and if the atmosphere could be regarded as having uniform density and a temperature equal

[1] *Astrophysical Journal*, 34, 374, 1911.

[2] *Annals of the Astrophysical Observatory of the Smithsonian Institution*, 2, 1908.

to that of the earth's surface, we should conclude that the transmissive power of the atmosphere is about 30 per cent.

But now the temperature of the atmosphere is falling off with the height above sea-level and a part of the observed nocturnal radiation is not transmitted entirely through the atmosphere, but merely to its colder layers. The effective radiating layer of the atmosphere may be regarded as having a certain temperature T, which is less than the temperature of the surface of the earth. It is difficult to give a definite value for this temperature T. From the observations of Pernter and Trabert[1] on the atmospheric radiation at different heights above sea-level, we may, however, conclude that a very small part of the radiation that reaches the earth from the atmosphere has its origin in layers lying at a greater altitude than about 3000 m above sea-level. At a height of 3000 m (top of Sonnblick) they find the atmospheric radiation to be only about $0.12 \frac{\text{gr. cal.}}{\text{cm.}^2\,\text{min.}}$ and since the atmosphere absorbs strongly the wave-lengths which it itself radiates, it is probable that only a very weak part of this radiation reaches the earth's surface. The temperature-fall being about 0°.07 for 100 m, the temperature at 3000 m will be about 21° below that at sea-level and we may assign a mean value for the temperature of the effective radiating layer which lies about 10° below the temperature of the earth's surface. This assumption, which cannot be very far from the real conditions, leads us to consider about 0.06 gr. cal. of the nocturnal radiation as intercepted by colder layers of the lower atmosphere. Of the remaining 0.09 gr. cal. which probably are transmitted through the lower absorbing layers, a considerable part will be absorbed by the ozone in the higher and colder strata of the atmosphere. As has been shown by K. Ångström,[2] the ozone has a strong absorption band between 9 and 10 μ, which is in the region where the water-vapor is weakly absorbing. In the winter time, when the quantity of ozone is relatively great, this absorption will reach about 50 per cent in the region of selective absorption; in the summer time the absorption is

[1] *Sitzungsber. d. d. Wiener Akad.*, **47**, 1562, 1888.

[2] *Arkiv för matematik, astronomi och fysik*, p. 347 (1904); p. 395 (1904) (German language).

almost zero. We may, however, as a mean value put the absorbing power of the upper strata of the atmosphere equal to about 20 per cent, and we shall in this way come to the conclusion that about 0.07 gr. cal. or only about 14 per cent of the radiation from the earth's surface will escape the absorbing atmosphere and go out to space. This is under the assumption that the sky is clear. This value for the transmission, which is not far from that derived by Abbot and Fowle from the measurements on the absorptive power of the water-vapor, is naturally subjected to some variation and must be regarded as only approximate.

Our considerations support us, however, in the belief that the transmission for clear sky seldom is greater than 25 per cent and seldom is less than about 5 per cent.

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December 1912

ON THE LONG-PERIOD VARIABLE STARS

In vol. 67 of the *Monthly Notices* (1907) Professor H. H. Turner has discussed the light-curves of some long-period variable stars. He starts from the generally acknowledged theory, which explains the light-fluctuations of these stars as being caused by periodic variations in the number and extension of sun-spots and faculae in their photospheres. Turner supposes that the "Spoerer law" of the distribution of sun-spots is valid for all these heavenly bodies. Then he shows how the orientation in space of the axis of rotation of a star will influence the type of the light-curve of the star. The extreme cases occur when the star is seen directly from its pole and when it is seen equatorially. Turner at last gives, as a distinguishing feature, the formula

$$\alpha=\frac{2(M-m)-P}{P},$$

where M signifies the time of maximum, m, the time of the preceding minimum, and P, the period. Then the value of α indicates the orientation of the axis of rotation with respect to the line of sight. α may vary between the limits $+0.25$ and -0.70. A large value of α indicates that the star is seen essentially from the

pole, while a small value of a will be found if the star is seen nearly equatorially. Turner applied this formula to a considerable number of the known long-period variable stars, and he arrives at the interesting conclusion that the axes of these stars are roughly oriented parallel to the plane of the Milky Way. I have made some further investigations concerning this matter in order, if possible, to discover any new relation between the given quantities. My thought has been, briefly expressed, that the orientation of the axis of rotation of the star must influence its light-curve in another way than by displacing the time of the maximum with respect to that of the minimum. The difference between the intensities of the light at maximum and at minimum must be much greater in case of an equatorial view than in case of a polar view when, as we know, everything will be presented along the edge of the disk of the star and, as Turner indicates, is seen very greatly foreshortened and when the brightness at maximum (at any rate, when caused by faculae) is essentially decreased by the absorption in the atmosphere of the star. He has, as far as I can see, not made use of this fact in the final discussion. He gives the data for such an investigation in the two lists of stars having large and small values of a. The only thing that remains to be done is to write beside the given values of a the values of $B-b$, where B signifies the maximum and b the minimum brightness of the star in question expressed in star magnitudes. This I have done and I find the values given in the following tables. The values of B and b are taken from the list of elements of variable stars given in the *Annuaire du Bureau des longitudes* for the year 1909.

a	Star-Names	$B-b$	R.A.
+0.25	*X Ophiuchi*	2.1	18^h34^m
0.22	*V Cephei*	0.7	23 52
0.19	*RS Librae*	6.0	15 18
0.18	*W Scorpii*	4.1	16 6
0.17	*V Ophiuchi*	2.9	16 21
0.16	*S Carinae*	3.1	10 6
0.13	*S Arietis*	6.6	1 59
0.12	*T Cassiopeiae*	4.0	0 18
0.11	*T Capricorni*	4.2	21 17
0.10	*S Cephei*	3.6	21 36
0.08	*T Cephei*	3.7	21 8
0.08	*V Tauri*	4.7	4 46

a	Star-Names	$B-b$	R.A.
+0.07	*X Capricorni*	6.2	$21^h\ 3^m$
0.07	*W Cygni*	0.8	21 32
0.07	*U Boötis*	3.3	14 50
0.05	*V Cygni*	5.4	20 38
0.05	*R Camelopardalis*	5.6	14 25
0.03	*R Aurigae*	5.9	5 9
0.03	*W Cassiopeiae*	3.6	0 49
0.02	*R Sagittarii*	2.0	19 11
−0.19	*T Arietis*	1.3	2 43
0.19	*S Piscium*	6.0	1 12
0.20	*V Boötis*	3.0	14 26
0.20	*U Orionis*	6.0	5 50
0.22	*R Aquilae*	4.6	19 2
0.22	*S Hydrae*	4.1	8 48
0.22	*Y Virginis*	5.3	12 29
0.23	*R Canis minoris*	2.3	7 3
0.25	*o Ceti (Mira)*	5.5	2 14
0.26	*R Centauri*	6.1	14 9
0.27	*U Cassiopeiae*	7.0	0 41
0.27	*R Cygni*	7.1	19 34
0.27	*V Lyrae*	6.4	19 5
0.27	*R Ursae majoris*	5.8	10 38
0.31	*R Cancri*	5.0	8 11
0.34	*R Comae*	6.3	12 0
0.34	*S Coronae*	5.3	15 17
0.35	*R Geminorum*	6.3	7 1
0.42	*R Andromedae*	8.7	0 18
0.63	*S Tauri*	4.0	4 24 (value of a doubtful)

If we divide these stars in groups and take the means of $B-b$ we shall have the following table:

a	$B-b$	Number of Stars in the Group
+0.20 to +0.25	1.40	2
+0.15 +0.20	4.03	4
+0.10 +0.15	4.60	4
+0.05 +0.10	3.74	5
+0.00 +0.05	4.50	5
−0.19 −0.24	4.06	8
−0.24 −0.29	6.31	6
<−0.29	5.93	6

And really, the small values of a correspond with large values of $B-b$ and inversely. This result seems to me very interesting. It shows the general supposition of the cause of the light-variations of these stars to be correct. Professor Turner's beautiful theory

has given us the means of verifying this hypothesis in another way than that usually followed by the modern astrophysicist who if possible makes his investigations by means of spectrum analysis. As we know, the spectroscope has revealed the great accordance of the spectra of the sun-spots with those of the stars of the third type, to which the majority of the long-period variable stars belong. If we acknowledge that this accordance demonstrates that the variation of the brightness of these stars is caused by increments and decrements of the "solar activity" on these heavenly bodies, we must hereafter acknowledge Turner's results to be nearly correct, as the criterion found above is fulfilled. This fact is of the greatest cosmogonical interest. The next step forward in this matter may be to inquire if the axes of rotation of these stars are oriented haphazard in planes roughly parallel to the galaxy or if they favor any direction in these planes. I do not think, however, that the material at present at our disposal, consisting of records of stars of this type lying in the plane of the Milky Way, is sufficient for such a delicate inquiry.

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REVIEWS

Conférences sur quelques thèmes choisés de la chimie physique pure et apliquée. Par SVANTE ARRHENIUS. Paris: Librairie Scientifique A. Hermann et Fils, 1912. Pp. 112; figs. 14; tables 7.

In this brochure of 112 pages there are brought together five lectures recently delivered at the Sorbonne by the distinguished Swedish savant. As may be inferred from their titles, the five essays cover a wide range of subjects: (I) "La théorie moléculaire"; (II) "Les suspensions et les phénomènes d'adsorption"; (III) "L'Énergie libre"; (IV) "Les atmosphères des planètes"; (V) "Les conditions physiques sur la planète *Mars*."

The first lecture is essentially a historical sketch which commences with the Greek philosophers Leucippus and Democritus and traces the development of the molecular theory to its present status. The chief interest naturally lies in the more recent advances, and here Arrhenius shows a superficial reading of the subject. If he had only read the résumé in the *Jahrbuch der Radioaktivität* he would have known that Ehrenhaft's critique of Millikan does not hold, for the variation in the observed readings was not due to any variation in the charge itself, which Millikan has since shown to be constant, but to variable readings caused by Brownian movements. Upon this apparent irregularity as an established foundation, Arrhenius works up a possible superstructure of theory. But that superstructure falls as the foundation is removed. As brought out by Arrhenius himself at the close of the chapter, the latest researches of Millikan have corrected this irregularity and have established the constancy of the electric charge. The wonder is that so much consideration was given to this irregularity.

The discussions of the second and third lectures are chiefly chemical in nature and are less within the field of astrophysics than the treatment of the atmospheres of the planets in the fourth lecture and the physical conditions on the planet *Mars* in the fifth. The general discussion in both of these last is based upon the theory of Laplace and stands or falls as that famous hypothesis withstands or goes down before the very grave objections which have arisen in recent years. To those who still

believe in the Laplacian hypothesis, much of this discussion may be acceptable; but to those who do not accept it as law and gospel, but rather regard it as now on trial for even a plausible standing, the conclusions so confidently and complacently built upon it seem no more secure than the foundation.

The treatment of terrestrial atmospheres and early terrestrial conditions is a restatement of the view made familiar long ago by Dana and others, with a few modern qualifications. The author either seems to be unaware of the difficulties confronting that time-honored view which have been pointed out in recent years, and the alternatives which have been proposed to meet some of these difficulties, or else prefers to ignore them and plunge ahead with free and familiar phrasing. He slides easily by the difficulty of the earth's incapacity to hold at any one time sufficient hydrogen, hydrocarbons, and cyanogen to produce, by combination with oxygen, the waters of the globe, which in the vaporous state would amount to at least 200 times the present atmosphere, and the carbon dioxide of the coal and limestone beds, which would amount to perhaps 50 times the earth's present atmosphere. He ignores the difficulty of accounting for the free oxygen which united with the hydrogen, hydrocarbons, and cyanogen to furnish the water and carbon dioxide; as well as the difficulty of starting vegetable life on a globe surrounded by an oxygenless atmosphere. He seems to see no infelicity in retaining carbon dioxide and other gases in large quantities within a globe which has been subjected to long-continued boiling before a solid crust formed upon it.

The gloomy picture of the "dead planet" *Mars*, supposed to have lost most of its atmosphere, is held up before us as the image of our globe in its period of decline. A discussion of the so-called canals comes to the front. In seeking rectilinear lines on the earth to compare with the supposed canals on *Mars*, Arrhenius seizes upon the geotectonic lines. If really carried to its proper geological conclusion, this leads to the hypothesis that the canals are analogous to such terrestrial features as the rift valleys like the Red Sea and Lake Tanganyika, a conception which has already been entertained by others.

The question of whether the faulted valleys are partially filled with water as on the earth and hence in any sense "canals," is pretty effectually answered by Campbell's careful observations on the summit of Mt. Whitney where, under very favorable conditions, he failed to detect a trace of water vapor in the Martian atmosphere.

The yellowish areas on the surface of the planet *Mars* are explained by Arrhenius as due to desert sands analogous to the great Khévir in

Persia. The dark bluish-green color assigned to the canals and Martian lakes he supposes may be due to the action of gaseous emanations along the fissures. He suggests that hydrogen sulphide and other reducing agents escaping from fissures might have transformed the iron salts in the neighborhood of these lines into bluish-green sulphides.

R. T. CHAMBERLIN

Radioactive Substances and Their Radiations. By E. RUTHERFORD. New York: Putnam, 1913. Pp. i–vii+1–700. $4.50.

A new book on radioactivity written by the foremost authority in this field, and after a lapse of eight years since the appearance of the last edition of his former treatise, is almost as notable an event as the discovery of a new radioactive product. But despite the fact that Rutherford has written what is practically a new book, instead of merely revising the old one, and despite the fact that the subject is now just twice as old as it was when the former book was written, the present treatment does not show anywhere any radical change of front in the interpretation of radioactive phenomena. This is because radioactivity, like the other grand divisions of physics, has probably already passed the period of revolutionary changes and is likely to grow henceforth by the process of accretion. In other words, the correct interpretation of the main radioactive phenomena has doubtless already been given.

The book in hand, then, differs from its predecessor chiefly in incorporating the advances of the past eight years without omitting much of what the other book contained. These advances have had to do chiefly with increases in the amount and accuracy of our knowledge of the radiations from active substances, the nature of their absorption by matter, and of their connection with the transformations; with the discovery of methods of counting single α particles; with the discovery and careful study of the phenomena of recoil; and with the extension through these methods of the known products of radioactive change from 20 in 1905 to 32 in 1913.

The chapter headings are: (i) "Radioactive Substances"; (ii) "Ionization of Gases"; (iii) "Methods of Measurement"; (iv) "Alpha Rays"; (v) "Beta Rays"; (vi) "Gamma Rays"; (vii) "Properties of the Radiations"; (viii) "Continuous Production and Decay of Radioactive Matter"; (ix) "Radioactive Gases"; (x) "Active Deposits"; (xi) "Theory of Successive Transformations"; (xii) "Uranium, Ionium and the Origin of Radium"; (xiii) "Radium and Its Emanation"; (xiv) "Active Deposit of Radium"; (xv) "Actinium and Its Products"; (xvi) "Thorium

and Its Products"; (xvii) "Production of Helium and Emission of Heat"; (xviii) "General Results and Relations"; (xix) "Radioactivity of the Earth and Atmosphere." This book will unquestionably be the standard work on radioactivity for the next half-dozen years.

R. A. MILLIKAN

Die Mathematik im Altertum und im Mittelalter. Von H. G. ZEUTHEN. Berlin und Leipzig: B. G. Teubner, 1912. Pp. 95. M. 3.

This monograph is one of six mathematical papers that are to appear under the editorship of Felix Klein of Göttingen, as part of the voluminous German publication known as "Kultur der Gegenwart."

With Zeuthen, Greek mathematics has been a favorite study. Over a quarter of a century ago he published a book on the conic sections in antiquity. In 1893 appeared the first edition of his history of ancient and mediaeval mathematics. Always known as an accurate writer, Zeuthen embodies in the present brief monograph the results of his mature scholarship. The fruits of recent historical research are carefully noted, such, for instance, as the use of symbols for zero in Babylonia at an earlier period than in India, the evolution of our + sign from the florescent *et* of Latin manuscripts, an account of the book on *Metrica* of Heron discovered by Schöne and published in 1903, a description of a book on *Method* due to Archimedes. This book on *Method* was supposed to have been irretrievably lost. The discovery of a copy of it by Heiberg in 1906 in Constantinople marks the most important advance in our knowledge of Greek mathematics in recent years. The manuscript in question is of parchment containing a tenth-century copy of the works of Archimedes. An attempt had been made to wash out the old script; the parchment was then used for liturgical writing. Fortunately the earlier writing shows with more or less clearness on most of the 177 leaves. Among other works of Archimedes, the parchment contains the *Method*, which is of interest to us as disclosing for the first time the steps by which Archimedes worked his way to the discovery of his great theorems with their rigorously scientific proofs. The *Method* affords a glimpse of the processes employed in the workshop of the greatest of ancient mathematicians; it rests upon the use of infinitesimals and of steps akin to those of the integral calculus.

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NOTICE

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Articles written in any language may be accepted for publication, but unless a wish to the contrary is expressed by the author, they usually will be translated into English. Tables of wave-lengths will be printed with the short wave-lengths at the top, and maps of spectra with the red end on the right unless the author requests that the reverse procedure be followed.

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A DETERMINATION OF THE PHOTOGRAPHIC MAGNITUDES OF COMPARISON STARS IN CERTAIN OF THE HAGEN FIELDS

By C. H. GINGRICH

To the ancient astronomer the features of the sky, except for the moon, the planets, and the appearance of an occasional comet, were unchangeable. This condition was attributable, not to a lack of diligence on the part of the observers, but to the fact that they did not have at their disposal any of the instruments of great precision which at present are indispensable to the advancement of science in general and of the science of astronomy in particular. However, changes of such a character were taking place as to be sure, sooner or later, to attract the notice even of the unaided eye.

In 1596 David Fabricius saw in the constellation *Cetus* an unusually bright star. When Bayer made the chart of this region seven years later a star in the same position was designated "*o*" (omicron), it being at that time relatively very faint. In 1609 Fabricius again saw the star bright. These facts constituted the evidence that the light received from this particular star was not constant in quantity. It has since been found to vary to such an extent that at certain periods at least a thousand times as much light is received from the star as at other periods. When, approximately a half-century later, the character of this change was understood and the period of the variation was fixed at about eleven months, the name *Mira*,

as an alternative to Bayer's letter, was assigned to the star to indicate that it was a cause of amazement that the light of the star should be variable.

For a long time *Mira Ceti* was the only star known to be variable. During the following two centuries others were noted but the study of variable stars was not systematized until the first half of the nineteenth century, when Argelander turned his attention to this subject and brought it into prominence as a new branch of astronomy. During the latter part of the nineteenth century several catalogues of variable stars and the elements of their variation were published, one by Schönfeld in 1865 containing 113 variable stars, and three consecutive ones by S. C. Chandler, the latest in 1896 containing 393 stars.[1] *A Provisional Catalogue of Variable Stars* published by the Harvard College Observatory in 1903 makes reference to 1227 stars. During the year 1904 more than 400 were discovered at the Harvard Observatory as a result of a systematic examination of the photographic plates having as its object the detection of variables. This search for variable stars is still going on and they are being found in such large numbers that at present the total number of known variables is in the neighborhood of 4000. In his *Katalog und Ephemeriden veränderlicher Sterne für 1912*, Ernst Hartwig gives the elements and predicted times of maximum and minimum for 1912 of 1370 stars. With the number of variables being so rapidly augmented it is unsafe to assume that any particular star is not a variable. This is made the more emphatic by the recent discovery that stars which for a long time were considered as standards because of their seemingly absolute uniformity are also subject to change. Notable among these is *Polaris*, which was announced by Hertzsprung[2] as being subject to a slight variation. The change in brightness was subsequently confirmed by E. S. King[3] and by Stebbins.[4] According to the *H.C.O. Circular 174* the range of variability is about 0.11 magnitude in a period of nearly 4 days.

[1] *Astronomical Journal*, No. 379, 1896.

[2] *Astronomische Nachrichten*, **189**, 89, 1911.

[3] *Science*, **34**, 523, 1911; *Harvard Annals*, **59**, 249.

[4] Paper before the Astronomical and Astrophysical Society of America, December, 1911.

Because of the attention which the subject of variable stars was receiving, Rev. J. G. Hagen in 1890, then the director of the Georgetown College Observatory, Washington, D.C., now of the Specola Vaticana, Rome, undertook the preparation of an atlas which should be useful for identifying the variables and supplying sequences of comparison stars, thus facilitating the work of observing the variables. This *Atlas of Variable Stars* consists of 311 charts and a catalogue sheet for each. The charts are arranged in six series according to position in the sky and according to the brightness of the respective variables at maximum and at minimum, the sixth being a supplement. The charts of the fainter variables cover a region one degree square having the variable in the center. In this square all of the *B.D.* stars are plotted and later verified as to position provisionally by means of a five-inch equatorial and finally by means of the twelve-inch equatorial of the Georgetown College Observatory. In the central region one-half degree square are plotted, in addition to the *B.D.* stars, all the stars visible in the twelve-inch telescope. The positions of all the stars were determined by means of a glass reticle and a chronograph, as described in the prefaces of Series I, II, and III.

Not only the positions but also the relative magnitudes of the stars in these fields are given in this atlas. The stars are connected by sequences of brightness according to the method of Herschel and Argelander. The grades were changed by the linear formula,

$$\text{Magnitude} = a + b(\text{Grade} - C),$$

into magnitudes so that they should agree as nearly as possible with the *B.D.* scale between the seventh and the tenth magnitudes. In some cases stars as faint as the 13.5 magnitude on the linear scale adopted are plotted. For the fainter stars the indicated magnitudes are merely relative and are not meant to be a continuation of either the *B.D.* or the Harvard scale. The stars, however, serve the purpose of the practical observer, since they furnish the successive comparison stars for the variable as it changes its light-intensity, and, although they do not enable one to establish the magnitude of the variable at minimum, they furnish data for determining the magnitude in any photometric scale by means of the

sequences of grades. For one who desires to make visual observations of the variables these charts, together with the catalogue sheets which accompany them, furnish the necessary equipment as far as the identification of the variable and the choice of suitable comparison stars are concerned.

In recent years photographic methods have invaded nearly every domain of astronomical research so that now there is scarcely any branch of the science which cannot be pursued more successfully by use of the photographic plate than visually. The relative merits of the two methods are rather obvious and have been treated elsewhere, so they will not be discussed here. The investigations of the light-changes in variable stars and the determination of their light-curves and hence their periods are facilitated very greatly by photographic processes. In order to study the variables photographically, however, it is necessary to have at hand data corresponding to those which the Hagen *Atlas* furnishes for the visual work. For the identification of the stars in question the charts still serve, but, since in general there is a difference between the visual and the photographic magnitude of a star, the visual determinations do not furnish photographic standards. At the suggestion of Professor J. A. Parkhurst about two years ago, it was thought to be desirable to establish the photographic magnitudes of stars which might be used as standards for comparison in the Hagen fields. It was with this object in view that the present work was begun, although up to the present time it has been possible to accomplish the end for a comparatively small number of the fields in the Hagen list.

The reason for the difference between the so-called photographic magnitudes and the visual magnitudes is inherent in the ordinary photographic plate. By the use of the properly chosen color-filter and a plate that is specially sensitized, the plate can be made to give visual results. However, this feature will be referred to later, and it will be seen that the use of the ordinary plate without a filter is more practicable. In ordinary commercial use of the photographic plates the speed of the plate is not such an important feature, since the operator can usually bring about conditions of light so that the plate will be affected sufficiently in the desired

time. In stellar photography, however, it is impossible to exercise any control upon the source of light, and in case of the fainter stars the quantity of light is so small that the exposure time must be correspondingly long. There is obviously a natural limit to the length of an exposure, since it is not advisable for quantitative work to resume an exposure after the intervention of a day. Consequently a necessary qualification of the plate to be used in stellar photographic work is that it must be rapid. The ordinary photographic plates which meet the condition are not equally sensitive to the light in the different parts of the spectrum, but have their greatest sensitiveness in the blue region. It follows directly that the light-effect of a given star is dependent upon its color as well as upon its intensity. Fig. 1 shows that the maximum sensitiveness of the Seed plate, the kind that was used in this work, lies well toward the violet end of the visible spectrum in the neighborhood of λ 4300. On the other hand, it is a physiological fact that the normal eye has its maximum sensitiveness to the light of the yellow-green part of the spectrum. From these considerations it is seen that the scale of photographic magnitudes and the scale of visual magnitudes will necessarily diverge, and that the difference between them in a given case will depend upon the color of the star in question. But the color of the star is merely an indication of more essential characteristics, namely, its chemical constitution and temperature. These conditions are portrayed in the spectrum of he star. The three factors—the photographic magnitude, the visual magnitude, and the spectrum—which pertain to a star are seen to be related, and if the relation is known it is possible, having given any two, to determine the third. This relation has been

(*a*)

(*b*)

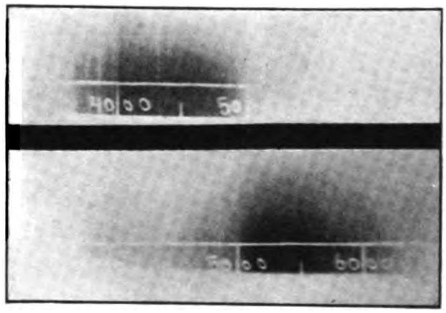


FIG. 1

(*a*) Region of maximum sensitiveness of Seed plates.

(*b*) Region of maximum sensitiveness of Cramer trichromatic plates with color-filter.

carefully studied by King,[1] by Parkhurst,[2] and by Schwarzschild.[3] The determination of photographic magnitudes therefore is not a separate and unrelated branch but is intimately connected with the determination of visual magnitudes and spectral type.

The plan of the work was necessarily conditioned upon, if not entirely determined by, the equipment which was at hand. The instruments which were best adapted to the present undertaking were the six-inch Zeiss ultra-violet camera,[4] and the two-foot reflector.[5] The camera was used for the brighter stars. Because of the short focus, it afforded a large usable field, thus making it possible to find standards, upon which to base the subsequent magnitudes, on the same plate with the variable. This instrument made it possible to use stars which were situated three degrees from the axis with a maximum correction for the distance from the axis of 0.32 magnitude. The usable field of the reflector being very much smaller, it was necessary to establish new standards on the camera plates, which should be near enough to the variable to be used as standards on the reflector plates. The plan, therefore, was to take a series of plates with the camera with proper exposure to determine magnitudes of stars near the variable. The original plan was to make three series of exposures with the reflector with apertures 12, 18, and 24 inches, respectively, for the purpose of passing constantly to fainter stars and necessarily extending the measures over smaller fields. It was found, however, that, owing to the uncertainty in focusing closely enough and because of the distortion of the field when the full aperture was used, it was inadvisable to use more than 12 inches aperture. The reduction from 24 inches to 12 inches aperture reduces the light-effect in the ratio of 5 to 1 approximately, hence the exposure time was greatly lengthened, although not in the same ratio; with the result that it was not possible to measure as faint stars as would have been possible if the original plan had been feasible.

[1] *Harvard Annals*, **59**, 180.

[2] *Astrophysical Journal*, **27**, 169, 1908; **37**, 217, 1912.

[3] *Aktinometrie*, B, p. 19.

[4] *Astrophysical Journal*, **36**, 171, 1912.

[5] *The Study of Stellar Evolution*, Hale, p. 43.

At the outset it was necessary to have stars whose magnitudes were known so that they might serve as a foundation upon which to build. These standard stars were selected according to the condition that the photographic magnitude and the visual magnitude of stars between 5.5 and 6.5 whose spectrum is of the first type, or of class A0, shall be the same. This definition of the starting-point of photographic magnitudes was adopted by the Committee on Magnitudes of the Astrographic Chart,[1] and it has now become essentially the "International System." This plan then made it possible to use the visual magnitudes of the white stars as determined by Müller and Kempf (*Potsdam Publications*, 17), in which are given their visual determination of all the *B.D.* stars of 7.5 magnitude or brighter. From this large list it was possible to find standards for the camera plates in all the fields that were undertaken. The plan adopted applied strictly only to white stars, that is, to stars of class A0. In order to determine in each case which of the bright stars were of this class an objective-prism plate[2] of each field was taken. In some cases it was not possible to find a sufficient number of stars in class A0, but in only one case were stars used which were farther advanced than A5. In all cases corrections were made for the deviation from class A0, according to a spectrum correction determined by Parkhurst. During the progress of this work a new determination of the spectrum correction[3] extending to stars of class M was made by Parkhurst, which so accurately accounts for the color-index that any of the Müller and Kempf stars might now be used with the same assurance as stars of class A0, provided only that the spectral type is known.

The camera plates were taken inside the focus[4] according to the methods adopted by Parkhurst and Jordan. The star images on the plates are circular and all essentially of the same size, about 1.2 mm in diameter. The difference in the light-intensity is indicated by the difference in opacity of the images and not by the size. In addition to exposing the plate to the sky, a series of

[1] *Astronomische Nachrichten*, 186, 40, 1910.

[2] *Popular Astronomy*, 19, 595, 1911.

[3] *Astrophysical Journal*, 36, 217, 1912.

[4] *Ibid.*, 36, 171, 1912.

twenty images resembling the star images was put upon the plate with a Spurge sensitometer in the laboratory before development.[1] The artificial stars were also of different densities and the steps between them known. All of these images were measured in the Hartmann "Mikrophotometer,"[2] and from the scale-readings and the known ratio of light-intensity of the artificial images the curve was made to which to refer the standard stars and those whose magnitudes were desired on that plate. From the first to the last of the artificial stars there is a gradual increase in opacity. The range is somewhat greater than can be measured with the wedge in the "Mikrophotometer," so that if the first are measurable the last are too dense, and if the last are measurable the first are too faint. Since, as would naturally be expected, there is a similarity in the form of the reduction-curve from the different plates, some of the plates were reduced by using the mean curve from a number of plates. In most cases, however, the curve was drawn for the individual plate from the measures of the images upon it. During the progress of this work an arrangement was devised for rotating the sensitometer during the laboratory exposure to avoid any illusory results in the sensitometer images which would arise if the plate containing the openings were not uniformly illuminated. Fig. 2 shows the curve which was made from the measures on plate UV 987. From this curve, which is typical of all the curves,[3] it may be seen that, except in the upper and lower parts of the curve, very accurate differences in magnitudes are indicated, since differ-

[1] *Astrophysical Journal*, **26**, 244, 1907.

[2] *Ibid.*, **36**, 171, 1912.

[3] During the time which intervened between the preparation and the publication of this paper, Professor Parkhurst has been studying the effect upon the particular brand of plates used in this work due to a variation in the exposure time. The results of the investigation up to the present seem to indicate that the gradation of the plate varies with the exposure time, in such a way that the contrast increases with the exposure. This may later be found to necessitate a slight correction to the magnitudes derived from the extra-focal plates, since the star images on these plates, exposed from 30 to 120 minutes, are compared with the sensitometer images, exposed a few seconds. It may also modify the results obtained from focal measures, since the value of *b* used in the reductions was also derived from exposures much shorter than the star images. This correction, if needed at all, will be relatively a small one, and may be applied as a percentage correction, starting from the magnitudes of the standard stars for the extra-focal plates, as given in the catalogue sheets.

ences in opacity corresponding to 0.1 or 0.2 mm in the scale-reading could easily be detected in measuring.

Two corrections were applied to reduce each star to the center of the plate, the plate having been placed in the camera so that its center was in the axis of the lens. The one correction was made

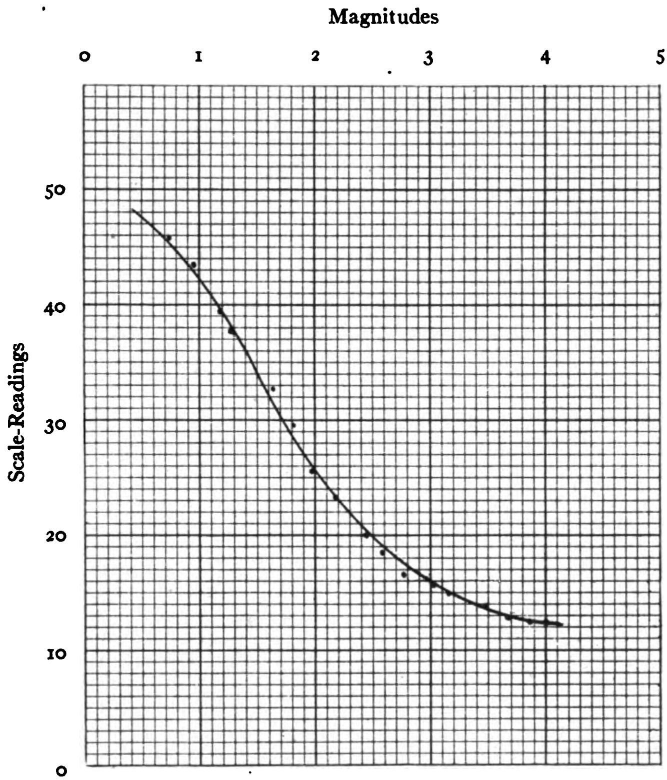


FIG. 2.—Reduction curve from measures of extra-focal images, made with the Hartmann "Mikrophotometer."

with reference to ρ, the distance from the axis, and the other with reference to the differential zenith distance. The correction for ρ was determined in the more or less familiar way of making a series of exposures of the same duration on some bright star, usually *Polaris*, the camera being moved in declination between the exposures in order to bring the images at varying distances from the

axis. The time consumed in making such a series did not exceed eight minutes at most, so that it could safely be assumed that on a clear night there would be no noticeable change in transparency in that short time. Nor would any slight variation in the star such as was mentioned in the case of *Polaris* have any appreciable effect in that period. Hence any difference in the various images would be due to the difference in the distances from the axis. It is reasonable that such correction should be important because, when the plate is placed inside the focus, the edges of the plate are of necessity at a less distance from the focus than the center of the plate. This correction was determined by Parkhurst and verified by the writer by remeasurements and also by subsequent plates. The corrections have been used as follows:

TABLE I

$\rho°$	Δ Mag.	$\rho°$	Δ Mag.
0.0	0.00	1.6	0.09
.2	.00	1.8	.11
.4	.00	2.0	.14
.5	.01	2.2	.17
.6	.01	2.4	.20
0.8	.02	2.6	.24
1.0	.03	2.8	.28
1.2	.05	3.0	.32
1.4	0.07	3.2	0.36

The correction for differential zenith distance, that is for atmospheric absorption, is much smaller and is determined from the table given by Wirtz.[1] This correction has been small in all this work because the exposures were made as near the zenith as possible. It is, however, a systematic correction and needs to be applied.

The following form shows the method of reduction. The scale-readings of the sensitometer images are given from which the curve of Fig. 2 was drawn. The scale-readings of the film near the images measured are made for the purpose of detecting any marked variation in the opacity which sometimes occurs. The columns need no explanation except possibly $(O-s)_z$, in which O stands for the center of the plate and s for the star, the difference being taken with reference to the zenith distance. The column "Sp. Cor." is the

[1] *Astronomische Nachrichten*, 154, 361, 1901.

spectrum correction, the stars not being purely of class Ao. The column "*M*o" represents the quantity to be added to the magnitudes of the plate in order to bring them to the scale of the adopted standards.

TABLE II

REDUCTION SHEET FOR CAMERA EXTRA-FOCAL PLATE

UV 987 *U Cancri* $\alpha = 8^h30^m$ $\delta = 19^\circ.2$ 1912 April 10 Seed 30

C.S.T. = $8^h.4$ Sid. T. = $9^h.7$ H.A. = $1^h.2$W $z = 26^\circ.0$ $q = 36^\circ$ $\frac{\Delta M}{\Delta z} = 0.006$

ARTIFICIAL STAR IMAGES

No.	Scale-Reading Film	Scale-Reading Image	No.	Scale-Reading Film	Scale-Reading Image
1..........	11.5	12.4	11.........	10.8	25.5
2..........	11.3	12.3	12.........	10.8	29.5
3..........	11.2	12.8	13.........	11.1	32.6
4..........	11.1	13.7	14.........	10.9	37.8
5..........	11.3	14.9	15.........	11.0	39.4
6..........	11.0	15.6	16.........	11.0	43.5
7..........	11.0	16.5	17.........	11.1	45.8±
8..........	10.8	18.4	18.........	....	....
9..........	11.1	19.9	19.........	....	....
10..........	11.0	23.2	20.........	....	....

B.D. Stars	Scale-Reading Film	Scale-Reading Image	Δ Mag. from Curve	ρ	$(O-s)_z$	Cor. ρ	Cor. z	Corr'd Δ Mag.	P.D. Mags.	Sp. Cor.	M°
20°2178.....	11.3	37.6	1.33	1°.4	+1°.2	0.07	+0.01	1.41	6.92	+0.14	5.65
20°2172.....	11.3	33.8	1.53	0.6	+0.7	0.01	0.00	1.54	7.07	+0.23	5.76
19°2053.....	11.4	34.7	1.48	0.7	−0.3	0.01	0.00	1.49	6.94	+0.19	5.64
Mean...	......	......	......	....	......	.....	......	.....	.....	......	5.68
Hagen Stars									**Mags.**		
3..........	11.3	14.5	3.13	0.9	−0.8	0.03	0.00	3.15	8.83	......	....
4..........	11.4	14.4	3.16	0.8	−0.7	0.02	0.00	3.18	8.86	......	....
6..........	11.3	12.2	4.08	1.0	−0.8	0.03	0.00	4.11	9.79	......	....

With the standards determined from the infra-focal images it was possible to pass to fainter stars by means of plates taken in focus on the two-foot reflector. In order to secure as large a field as possible, and in order not to overexpose the brighter stars, a series of short exposures with diaphragm giving 12 inches aperture was made. Afterward, by using magnitudes determined from this

series, the magnitudes of still fainter stars were determined from a series of plates having an exposure of at least an hour. A few exposures were made with an aperture of 18 inches, but for reasons mentioned above it was better to use only the 12-inch aperture and nearly all the plates that contribute to the results were taken with that aperture.

The focal images were then measured under the Zeiss-Romare machine.[1] The machine being equipped with two screws, both the vertical and horizontal diameters of the images were measured and the mean adopted. It is very difficult to obtain plates on which the images are perfectly circular. Any deviation from perfect roundness appears in the magnified image which was measured. Only in exceptional cases, however, will the discrepancy amount to more than 15 per cent of the mean, and in most cases it was much less. The reduction to magnitudes was made by the formula

$$\text{Magnitude} = a - b\sqrt{D},$$

in which b is a constant depending upon the instrument and the kind of plate used, and a is a constant which depends upon the exposure. The justification for the use of this formula for the combination of instrument and plate used is found in an investigation by Parkhurst[2] made some time ago.

The value of the constant b was determined from a number of plates by two independent methods. The first method was based upon measures of plates of the *Pleiades*. The images of a list of the stars whose photographic magnitudes were known were measured. By plotting as abscissas the values of $\sqrt{D}$ derived from the plate and as ordinates the magnitudes determined by Schwarzschild on the absolute scale, using the largest range that could be derived from the plate, it was possible to determine the increment in magnitude corresponding to a given increment in $\sqrt{D}$. From the formula, we have

$$M = a - b\sqrt{D}$$

$$M + \Delta M = a - b(\sqrt{D} - \Delta\sqrt{D}).$$

[1] *Astrophysical Journal*, 36, 175, 1912.

[2] *Ibid.*, 31, 21, 1910.

By subtraction,

$$\Delta M = b\Delta\sqrt{D}$$

$$b = \frac{\Delta M}{\Delta\sqrt{D}}\,.$$

Theoretically it would be necessary to use only two stars to determine b in this equation, but in practice as many as were available were used. A straight line was found to represent the mean of all the plotted points, thus justifying the form of the equation. From 14 series of *Pleiades* images the mean value of b was found to be 0.897 with a probable error of ± 0.004. The second method of determining b was the application of a device used by Wirtz[1] and by Schwarzschild[2] and by others. The essential feature of the method is the interposition of a medium which decreases the light of the star by a known amount. This medium must be such as not to have any selective absorption, that is, it must reduce the light of all wave-lengths equally. A fine wire cloth or gitter with uniform meshes meets the requirement. In practice it was used in this work by fixing a piece of the gitter in a metal frame which was placed before the plate so as to bring the gitter at a distance of about 75 mm from the film. This distance was determined such as to prevent the overlapping of the diffraction images and the central image, which precaution was necessary in order to keep the central image free for measurement. From measurements of the constants of the gitter made by Parkhurst, Dr. Van Maanen, and the writer, the following values for the absorption in magnitudes were derived, respectively, 1.892, 1.877, and 1.864. The absorption of the gitter was further tested by Parkhurst with the Hartmann wedge photometer and was found to be 1.86 magnitudes. The value 1.87 was adopted in this work. The gitter used was large enough to cover only half the plate so that when exposed with the gitter half of the plate received free images and the other half received the gitter images. The method of using the gitter was as follows: first, to make an exposure having the gitter covering one-half of the plate and then, after reversing the gitter so as to cover the other

[1] *Astronomische Nachrichten*, **154**, 317, 1901.

[2] *Ibid.*, **183**, 297, 1910.

half, to make a second exposure of the same length as nearly as possible. An objection to the use of the half-gitter, pointed out by Schwarzschild, is the fact that near the middle of the plate there will be images part of whose rays were affected by the gitter but the rest of which were not so affected. These images are necessarily useless in the determination of b. These useless images fall in the region which is normally the best part of the field, which becomes a serious objection when the field is small at best, as in the case of the reflector. The difficulty would be removed by using a gitter over the entire plate during one exposure, and leaving the plate entirely free during the other. In this case it would be assumed that the conditions of seeing remain unchanged during the two exposures, which is also objectionable. In the former case the difficulty is definite and can be eliminated, but in the latter the error introduced is uncertain. Of the two, the former therefore seems to be the less objectionable. Usually in practice an entirely free exposure for a shorter time was made on the same plate and used according to the first method, thus furnishing a direct comparison between the two methods here used for determining the value of b. The free and the gitter images were measured and used for the determination of b as follows:[1]

$$M_1 = a_1 - b\sqrt{D_{1f}} \tag{1}$$

$$M_1 + 1.87 = a_2 - b\sqrt{D_{2g}} \tag{2}$$

$$M_2 = a_2 - b\sqrt{D_{2f}} \tag{3}$$

$$M_2 + 1.87 = a_1 - b\sqrt{D_{1g}} \tag{4}$$

(2)−(1)

$$1.87 = a_2 - a_1 + b(\sqrt{D_{1f}} - \sqrt{D_{2g}}) \tag{5}$$

(4)−(3)

$$1.87 = a_1 - a_2 + b(\sqrt{D_{2f}} - \sqrt{D_{1g}}) \tag{6}$$

Adding (5) and (6)

$$1.87 = \frac{b}{2}(\sqrt{D_{1f}} - \sqrt{D_{2g}} + \sqrt{D_{2f}} - \sqrt{D_{1g}}),$$

[1] M_1 = magnitude of star whose image is free in first exposure.
a_1 = value of a from first exposure.
D_{1f} = diameter of free images in first exposure.
D_{2g} = diameter of gitter image in second exposure.

from which b is readily found. From three plates which were investigated by this method the mean value of b was determined to be 0.914 with a probable error of ± 0.01. Since this method is independent of the actual magnitudes of the stars in question, and since the value of b agrees so closely with the value of b as determined from the magnitudes of the *Pleiades*, it furnishes evidence

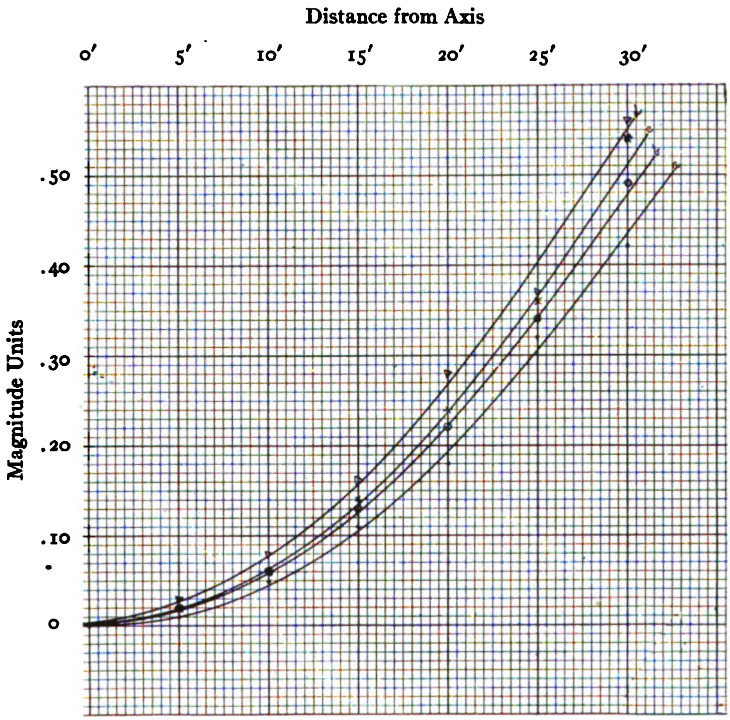


FIG. 3.—Correction curves for distance from axis on reflector plates

that the derived value of b used in the formula mentioned above leads to the determination of magnitudes on the absolute scale upon which the *Pleiades* magnitudes were based. The exposures in the latter case were also made on the *Pleiades*, although that was not necessary as any other group would serve as well, provided only that a suitable number of stars, preferably of the same spectral type, not differing too widely in magnitude, should fall within the

measurable field of the plate. From a combination of the values determined by the two methods, giving equal weight to each individual determination, the value 0.90 was adopted as the value of b to be used.[1]

In the case of the reflector plates the correction for the position of the star with reference to the axis is important. Twenty series of exposures were made for the purpose of determining this correction for the 12-inch aperture. A star near the pole was selected for this purpose so that it would be unnecessary to guide during the exposures. The star chosen was of such a brightness that the exposure time necessary was long enough so that the slight differences of exposures, due to the opening and closing of the slide, would be proportionately unappreciable, and of such a brightness also that the exposure time was not so long as to require for the series so much time that the conditions of seeing should change. A row of twenty images was made by moving the telescope in declination between the exposures, the telescope having been set so that the star should at some time in the series be in the axis. The correction was seen to depend upon the diameter of the image, so the series were made of images of different sizes. The curves in Fig. 3 show the mean values of the corrections for the different sizes of the images. From these curves it is seen that the correction becomes excessive for stars more than 30 minutes of arc from the axis, and for that reason stars so situated were not used. In some cases the stars whose magnitudes are given are more than 30 minutes of arc from the variable but they have been determined from plates so centered that the variable was not in the axis.

The following table of corrections was derived from the curves of Fig. 3, and was used for correcting the plates of 12 inches aperture. The first horizontal row indicates the size of the images; ρ indicates the distance from the axis in minutes of arc. The corrections are given in hundredths of a magnitude.

A similar correction was made for the plates taken with 18 inches aperture. On these plates stars more than 20 minutes of arc from the axis could not be used. The corrections in Table IV were found as the mean of sixteen series. These apply to images for which the value of $b\sqrt{D}$ is equal to 10.0. Since very few plates

[1] See footnote, p. 216.

TABLE III

TABLE OF CORRECTIONS FOR DISTANCES FROM AXIS

REFLECTOR FIELD. SEED PLATES. 12 INCHES APERTURE

$b\sqrt{D}$ / ρ'	7.75	8.00	8.50	9.00	9.50	10.00	10.50	11.50
1'....	00	00	00	00	00	00	01	01
2.....	00	00	01	01	01	01	01	02
3.....	01	01	01	01	01	02	02	03
4.....	01	01	01	01	02	02	02	03
5.....	01	01	02	02	02	02	03	04
6.....	02	02	03	03	03	03	04	05
7.....	02	02	03	03	04	04	05	06
8.....	03	03	04	04	05	05	06	07
9.....	04	04	05	05	06	06	07	08
10.....	04	05	06	06	07	07	08	09
11.....	06	06	07	07	08	09	10	11
12.....	07	07	08	08	09	11	11	12
13.....	08	09	10	10	10	12	13	14
14.....	09	10	11	11	12	13	14	16
15.....	11	12	13	13	14	15	16	18
16.....	12	13	14	15	16	17	18	20
17.....	14	15	16	17	18	19	20	22
18.....	15	16	18	19	20	21	22	24
19.....	16	18	20	21	22	24	25	27
20.....	18	20	22	23	24	26	27	29
21.....	20	20	24	26	27	28	29	31
22.....	22	24	26	28	29	30	31	33
23.....	24	26	28	30	31	32	33	35
24.....	26	28	31	32	34	35	36	37
25.....	29	31	34	35	36	37	39	40
26.....	32	34	36	38	39	40	42	44
27.....	34	37	40	41	42	43	45	48
28.....	38	40	43	44	45	46	48	51
29.....	41	43	46	47	48	49	51	53
30.....	44	46	49	50	52	53	54	58

TABLE IV

TABLE OF CORRECTIONS FOR DISTANCES FROM AXIS

REFLECTOR FIELD. SEED PLATES. 18 INCHES APERTURE

ρ'	Mag.	ρ'	Mag.
1...............	0.01	11...............	0.14
2...............	.01	12...............	.17
3...............	.02	13...............	.20
4...............	.03	14...............	.24
5...............	.04	15...............	.27
6...............	.05	16...............	.31
7...............	.07	17...............	.34
8...............	.08	18...............	.38
9...............	.10	19...............	.42
10...............	0.12	20...............	0.46

made with this aperture were used, the corrections for images of other sizes were not determined.

Since the usable field of the reflector never exceeds 1° in diameter and the plates in general were taken very near the meridian, none of the fields being south of 10 degrees north declination, the correction for differential atmospheric absorption was negligible.

The following form (Table V) is an example of the measurements and complete reduction of some of the stars on one of the reflector plates.

The columns marked x and y are respectively the horizontal and vertical diameters. Each of the numbers recorded represents the mean of three settings of the micrometer. The column "Mean D" is expressed in half-revolutions of the micrometer screw. The column "μ" is obtained by multiplying the preceding column by the factor 36.7 which converts the half-revolution units into thousandths of a millimeter.

TABLE V

REDUCTION SHEET FOR REFLECTOR PLATE

R2657 χ *Cygni* 1912 June 15, $11^h 58^m$ to $12^h 23^m$ C.S.T. 12 In. Apert.
Seed 30

Hagen No.	x	D_x	y	D_y	Mean D	μ	$\sqrt{D}$	$.90\sqrt{D}$	ρ	Corr'n ρ	Corr'd $b\sqrt{D}$	Mags. (C)	a
3 . . .	46.45		44.35										
	51.84	5.39	49.84	5.49	5.44	199.65	14.13	12.72	24	39	12.33	6.92	19.25
9 . . .	47.98		46.70										
	52.25	4.27	50.55	3.85	4.06	149.00	12.21	10.99	14	15	10.84	8.79	19.63
7 . . .	47.41		45.68										
	51.80	4.39	49.93	4.25	4.32	158.54	12.59	11.33	25	40	10.93	8.43	19.36
13 . . .	47.76		46.86										
	51.65	3.89	50.34	3.48	3.68	135.06	11.62	10.46	24	36	10.10	9.23	19.33
												Mags. (R)	19.39
20 . . .	48.60		47.45										
	52.25	3.65	50.81	3.36	3.51	128.82	11.35	10.22	06	03	10.19	9.20	. . . . . .
34 . . .	48.51												
	51.63	3.12	50.61	2.82	2.97	109.00	10.44	9.40	08	05	9.35	10.04	. . . . . .
27 . . .	48.22		47.53										
	50.65	2.43	49.75	2.22	2.33	85.51	9.25	8.32	10	06	8.26	11.13	. . . . . .
6 . . .	47.85		47.12										
	51.90	4.05	50.70	3.58	3.82	140.19	11.84	10.66	16	18	10.48	8.91	. . . . . .
26 . . .	48.04		46.90										
	51.64	3.60	50.11	3.21	3.40	124.78	11.17	10.05	22	30	9.75	9.64	. . . . . .

The column "ρ" expresses the distance from the axis in minutes of arc.

The column "Mags. (C)" indicates magnitudes derived from the camera plates. These magnitudes are used as standards on this plate.

The column "Mags. (R)" indicates the magnitudes derived from this plate.

In addition to the determination of photographic standards from the Seed plates taken with the Zeiss camera, a second series of plates was taken for the purpose of establishing visual standards. The method for accomplishing this end has been used at this observatory for some years.[1] It consists in placing immediately in front of the film of the color-sensitive plate a "visual luminosity" filter which was prepared especially for this purpose by R. J. Wallace. With this filter are used Cramer trichromatic plates. This combination is found by spectroscopic tests to have its maximum sensitiveness in the same region as the normal eye (Fig. 1), and for that reason leads directly to visual magnitudes, although they are determined photographically. These plates were taken in focus and measured on the same machine as the reflector plates. The formula

$$\text{Magnitude} = a - b\sqrt{D}$$

was used in this case also for reducing to magnitudes. The value of b was determined by the method of *Pleiades* magnitudes only. From sixteen series of measures the weighted mean of the value of b was found to be 0.515.

The stars used as standards on these plates were the same as those used for the photographic magnitudes. In this case, however, no correction was applied for the spectrum inasmuch as the question here was solely one of visual magnitudes. The stars whose magnitudes were derived on these plates were the same as those determined from the infra-focal plates taken with the camera. The original intention was to use these visual standards on a series of reflector plates made also with the color-filter. This plan has up to the present time not been carried out for the reason that the exposure times were necessarily very much lengthened because of

[1] *Astrophysical Journal*, **27**, 169, 1908.

the interposition of the color-filter. It was found that normally the trichromatic plates with the filter required nine times the exposure that was required by the ordinary plate. Unfortunately when the trichromatic plates were to be used the emulsions then obtainable were only about half as rapid as the normal emulsion, and consequently it would have been necessary to prolong the exposure time so much as to make it inadvisable to attempt the work. It is hoped that at some time conditions will be found more favorable for carrying out this plan. In the reductions corrections were applied for distance from the axis and for the atmospheric absorption due to the differential zenith distance. The former correction was determined by a method similar to that used for determining the corresponding correction for the infra-focal plates and for the reflector plates. As in the case of the reflector plates, it was found to depend upon the size of the image. The second correction is very small for the reason mentioned in the case of the photographic magnitudes, namely, that the plates were taken near the meridian, and, since all the fields cross the meridian at a considerable altitude, the extinction factor there is very small. This correction is made according to the visual extinction table given in the *Potsdam Publications*, 3, 285.

In the catalogue which follows (Tables VI–XV), in each field the first section of the table gives the list of standard stars used. The number under the Potsdam *Durchmusterung* refers to the serial number in *Publikationen des Astrophysikalischen Observatoriums*, Potsdam, 17. The color given is the visual estimate by the observers. The other columns need no further comment.

The second section gives the photographic magnitudes determined in this work. In the first column are given the numbers assigned to these stars in the Hagen *Atlas*. The second column gives the visual magnitude assigned by Hagen. They are given here for convenient comparison with the photographic magnitudes. The differences presumably are largely due to spectral type. A part may be due to different scales. In the third column are the weighted mean values determined from the photographic plates after applying a correction of −0.28 magnitude. It was found by Parkhurst that the mean correction necessary to reduce the Pots-

dam magnitudes to the International System was −0.27 magnitude. From a similar determination by Schwarzschild the correction was found to be −0.29 magnitude. Since the magnitudes here

TABLE VI

U CANCRI FIELD

$\alpha = 8^h 30^m 3^s$ $\delta = +19°14'.4$ (1900) Hagen Series II

STANDARD STARS

B.D. No.	*B.D.* Mag.	*P.D.* No.	*P.D.* Mag.	*P.D.* Color	Spectrum	Cor. for Spectrum	Photographic Magnitude
20°2178...	7.0	5204	6.92	GW	A3	0.14	7.06
20 2172...	7.1	5199	7.07	GW	A5	0.23	7.30
19 2053...	7.2	5166	6.94	GW	A4	0.19	7.13

MEASURED STARS

PHOTOGRAPHIC MAGNITUDES

Hagen No.	Hagen Mag.	Photog. Mag.	Instr.	No. of Plates	p.e.	Hagen No.	Hagen Mag.	Photog. Mag.	Instr.	No. of Plates	p.e.
2...	7.9	7.70	R	1	....	20...	9.9	11.17	R	1	....
3...	8.5	8.64	C	3	0.04	21...	10.0	11.47	R	1	....
4...	8.5	8.63	C	3	0.02	22...	10.0	10.87	R	1	....
5...	8.7	9.3	R	1	....	23...	10.0	10.78	R	1	....
6...	8.9	8.56	C	3	0.02	24...	10.1	10.71	R	1	....
7...	9.0	9.70	R	1	....	25...	10.3	11.03	R	1	....
9...	9.2	10.15	R	1	....	26...	10.4	11.20	R	4	0.10
10...	9.2	10.42	R	1	....	27...	10.4	11.26	R	1	....
11...	9.3	10.08	R	1	....	28...	10.5	11.84	R	1	....
12...	9.3	10.22	R	4	0.06	29...	10.5	11.19	R	1	....
13...	9.4	9.47	R	1	....	30...	10.8	10.97	R	4	0.08
14...	9.5	10.92	R	1	....	31...	11.0	11.78	R	4	0.10
15...	9.6	10.84	R	1	....	32...	11.0	11.93	R	1	....
16...	9.7	10.63	R	1	....	33...	11.1	11.55	R	4	0.11
17...	9.7	10.92	R	1	....	34...	11.1	11.98	R	4	0.10
18...	9.8	10.96	R	1	....	35...	11.2	11.91	R	4	0.11
19...	9.9	11.66	R	1	....	36...	11.8	12.40	R	4	0.09
						39...	12.3	12.43	R	4	0.08

VISUAL MAGNITUDES

Hagen No.	Hagen Mag.	Magnitude	Color-Index	Spectrum Inferred	Instr.	No. of Plates	p.e.
3.......	8.5	8.37	+0.27	A7	C	3	0.04
4.......	8.5	8.38	+0.25	A6	C	3	0.03

given were based upon Potsdam magnitudes as standards they are subject to the same correction. The mean correction, −0.28 magnitude, was adopted. In the column "Instr." C indicates the Zeiss camera, and R indicates the two-foot reflector. The column p.e. is designed merely to indicate in a general way the agreement of the plates. The number given is found by taking twice the greatest range on the plates and dividing by three times the number of plates. This is a close approximation to the usual probable error formula, which, however, presupposes a larger number of independent determinations than are used here. When the star has been measured on less than three plates, no probable error is given. When, as happens in a few cases, the star was measured on only one plate, the magnitude is given to the nearest tenth. The third section in the fields in which it appears, gives the visual magnitudes determined. In this section two additional columns are given. The column headed "Color-Index" gives the difference between the photographic and visual magnitudes. From this column by reference to Parkhurst's determination of the relation of color-index to spectral type, the next column, "Spectrum Inferred," is formed.

More than half of the stars of this field were measured on only one plate. However, the results given are entitled to more weight than would seem to be the case from a single plate, since a systematic correction was found from the stars that appear on the four plates and applied to the stars that appear on the one plate only so

TABLE VII

R CAMELOPARDALIS FIELD

$\alpha=14^h25^m6^s$ $\delta=+84°17'.1$ (1900) Hagen Series III

STANDARD STARS

B.D.		P.D.			Spectrum	Cor. for Spectrum	Photographic Magnitude
No.	Mag.	No.	Mag.	Color			
81°495....	6.8	7985	7.40	GW−	A1	0.04	7.44
83 431....	6.0	8003	5.87	GW+	F8	0.77	6.64
84 335....	7.5	8043	6.98	WG+	K2	1.33	8.31
85 234....	7.0	7506	7.85	WG−	G4	1.05	8.90
85 222....	7.0	7281	7.36	GW+	F5	0.63	7.99
84 311....	7.5	7331	7.42	WG−	F9	0.82	8.24
83 397....	6.5	7459	6.07	WG	G3	1.00	7.07

TABLE VII—*Continued*

MEASURED STARS

PHOTOGRAPHIC MAGNITUDES

Hagen No.	Hagen Mag.	Photog. Mag.	Instr.	No. of Plates	p.e.	Hagen No.	Hagen Mag.	Photog. Mag.	Instr.	No. of Plates	p.e.
1...	8.1	9.28	C	3	0.01	12...	9.9	11.11	R	7	0.07
2...	8.5	8.95	R	4	0.04	13...	10.1	11.51	R	5	0.08
3...	8.7	9.20	R	5	0.04	14...	10.4	11.69	R	4	0.06
4...	8.7	9.01	C	3	0.02	15...	10.6	11.93	R	2	....
5...	9.0	10.85	R	1	....	16...	10.7	12.3	R	1	....
6...	9.0	9.48	C	3	0.02	19...	11.2	12.9	R	1	....
7...	9.0	10.53	R	7	0.04	21...	11.3	12.5	R	1	....
8...	9.4	10.17	R	3	0.08	22...	11.4	12.6	R	1	....
9...	9.7	10.67	R	3	0.10	23...	11.6	13.1	R	1	....
10...	9.9	11.36	R	7	0.04	24...	11.7	12.7	R	1	....
11...	9.9	10.88	R	7	0.05	25...	11.9	13.0	R	1	....

that they too are reduced to the mean of the four. Because of the position of this field it was impossible to make any more exposures on it in the time remaining for the work.

In this field it was impossible to find a sufficient number of white stars to be used as standards. Consequently, in addition to the one star of spectral type A1, six other stars from the *P.D.* list whose spectra were well determined from objective-prism plates were used. The corrections for the spectral type were applied according to Parkhurst's curve. It is of interest to note that the photographic magnitudes of the Hagen stars 1, 4, and 6 based upon these standards differ by only 0.02, 0.03, and 0.01, respectively, from the magnitudes obtained for these stars if based directly upon the magnitudes of the standards as given in Parkhurst's *Zone Catalogue*.

TABLE VIII

RU HERCULIS FIELD

$\alpha = 16^h6^m3^s$ $\delta = +25°19'.9$ (1900) Hagen Series VI

STANDARD STARS

B.D.		*P.D.*			Spectrum	Cor. for Spectrum	Photographic Magnitude
No.	Mag.	No.	Mag.	Color			
23°2916...	7.0	8599	6.86	WG	G5	1.08	7.94
27 2597...	7.3	8554	7.86	GW−	F0	0.40	8.26

TABLE VIII—*Continued*

MEASURED STARS

PHOTOGRAPHIC MAGNITUDES

Hagen No.	Hagen Mag.	Photog. Mag.	Instr.	No. of Plates	p.e.	Hagen No.	Hagen Mag.	Photog. Mag.	Instr.	No. of Plates	p.e.
1...	...	8.21	C	4	0.03	19...	10.3	11.95	R	4	0.08
3...	8.5	10.02	R	6	0.04	20...	10.3	12.33	R	4	0.02
4...	8.7	9.46	R	6	0.09	21...	10.4	12.82	R	2	....
5...	8.8	9.49	R	5	0.06	22...	10.4	12.49	R	3	0.11
6...	8.9	9.98	R	5	0.06	23...	10.5	12.39	R	2	....
7...	9.0	10.6	R	1	....	24...	10.5	12.16	R	4	0.02
9...	9.4	10.82	R	6	0.04	25...	10.5	12.30	R	3	0.02
10...	9.5	11.5	R	1	....	26...	10.6	12.3	R	1	....
11...	9.5	11.5	R	1	....	27...	10.8	13.3	R	1	....
12...	9.6	11.03	R	6	0.04	29...	11.0	12.84	R	2	....
13...	9.8	12.2	R	1	....	30...	11.0	12.76	R	2	....
14...	9.8	11.54	R	6	0.08	31...	11.2	13.02	R	3	0.06
15...	10.0	11.9	R	1	....	32...	11.3	13.41	R	2	....
16...	10.0	11.64	R	6	0.07	33...	11.5	13.36	R	2	....
18...	10.2	12.21	R	4	0.07	34...	11.6	13.3	R	1	....
						35...	11.9	13.4	R	1	....

VISUAL MAGNITUDES

Hagen No.	Hagen Mag.	Magnitude	Color-Index	Spectrum Inferred	Instr.	No. of Plates	p.e.
1.......	...	7.50	0.71	F8	C	5	0.02

This field is exceptional in that no white, or even approximately white, stars, bright enough to be in the *P.D.*, appeared on the camera plate. The stars used as standards, as the spectrum column shows, are advanced beyond the stage of those usually used. The

TABLE IX

W HERCULIS FIELD

$\alpha=16^h31^m41^s$ $\delta=+37°32'.4$ (1900) Hagen Series III

STANDARD STARS

B.D.		*P.D.*			Spectrum	Cor. for Spectrum	Photographic Magnitude
No.	Mag.	No.	Mag.	Color			
37°2750...	5.7	8670	5.82	W+	A3	0.12	5.94
38 2811...	7.2	8785	7.72	GW	A2	0.08	7.80
37 2802...	7.5	8851	7.47	W+	A0	0.00	7.47

TABLE IX—*Continued*

MEASURED STARS

PHOTOGRAPHIC MAGNITUDES

Hagen No.	Hagen Mag.	Photog. Mag.	Instr.	No. of Plates	p.e.	Hagen No.	Hagen Mag.	Photog. Mag.	Instr.	No. of Plates	p.e.
1...	7.9	9.04	C	3	0.01	14...	9.5	9.95	R	3	0.02
2...	8.2	8.75	C	3	0.02	15...	9.5	11.31	R	3	0.01
3...	8.3	9.22	R	3	0.06	16...	9.8	11.48	R	3	0.07
4...	8.4	8.95	C	3	0.02	17...	9.9	11.02	R	3	0.04
5...	8.4	8.44	C	3	0.02	18...	10.0	11.08	R	3	0.07
6...	8.6	9.87	R	3	0.08	19...	10.3	11.79	R	4	0.01
7...	8.8	9.87	R	3	0.08	20...	10.4	11.40	R	3	0.06
8...	8.9	10.28	R	3	0.07	21...	10.5	11.58	R	3	0.07
9...	9.0	10.78	R	3	0.04	22...	10.7	12.36	R	2	....
10...	9.2	10.98	R	3	0.04	24...	11.0	12.98	R	2	....
11...	9.2	10.28	R	3	0.04	25...	11.2	12.58	R	2	....
12...	9.3	10.84	R	3	0.04	27...	11.4	12.96	R	2	....
13...	9.4	10.64	R	3	0.06	28...	11.4	12.84	R	3	0.08
						29...	11.6	12.89	R	3	0.05

VISUAL MAGNITUDES

Hagen No.	Hagen Mag.	Magnitude	Color-Index	Spectrum Inferred	Instr.	No. of Plates	p.e.
1.......	7.9	7.71	+1.33	Ko	C	3	0.02
2.......	8.2	8.33	+0.42	Fo	C	3	0.03
4.......	8.4	8.62	+0.33	A8	C	3	0.01
5.......	8.4	8.62	−0.18	B7	C	3	0.05

estimates of these spectral types were verified by Parkhurst and the corrections applied from the most recent curve so that the magnitudes in this field are, nevertheless, on the same basis as those of the other fields in this list.

TABLE X

X CYGNI FIELD

$\alpha = 19^h46^m44^s$ $\delta = +32°39'.7$ (1900) Hagen Series III

STANDARD STARS

B.D. No.	B.D. Mag.	P.D. No.	P.D. Mag.	P.D. Color	Spectrum	Cor. for Spectrum	Photographic Magnitude
33°3572...	6.7	10960	6.38	W	Ao	0.00	6.38
32 3662...	7.0	11171	7.52	W+	Ao	0.00	7.52
31 3779...	6.5	11003	7.11	W+	Ao	0.00	7.11
35 3786...	7.0	10978	6.88	GW	Ao	0.00	6.88
34 3778...	6.8	11084	7.38	W	Ao	0.00	7.38

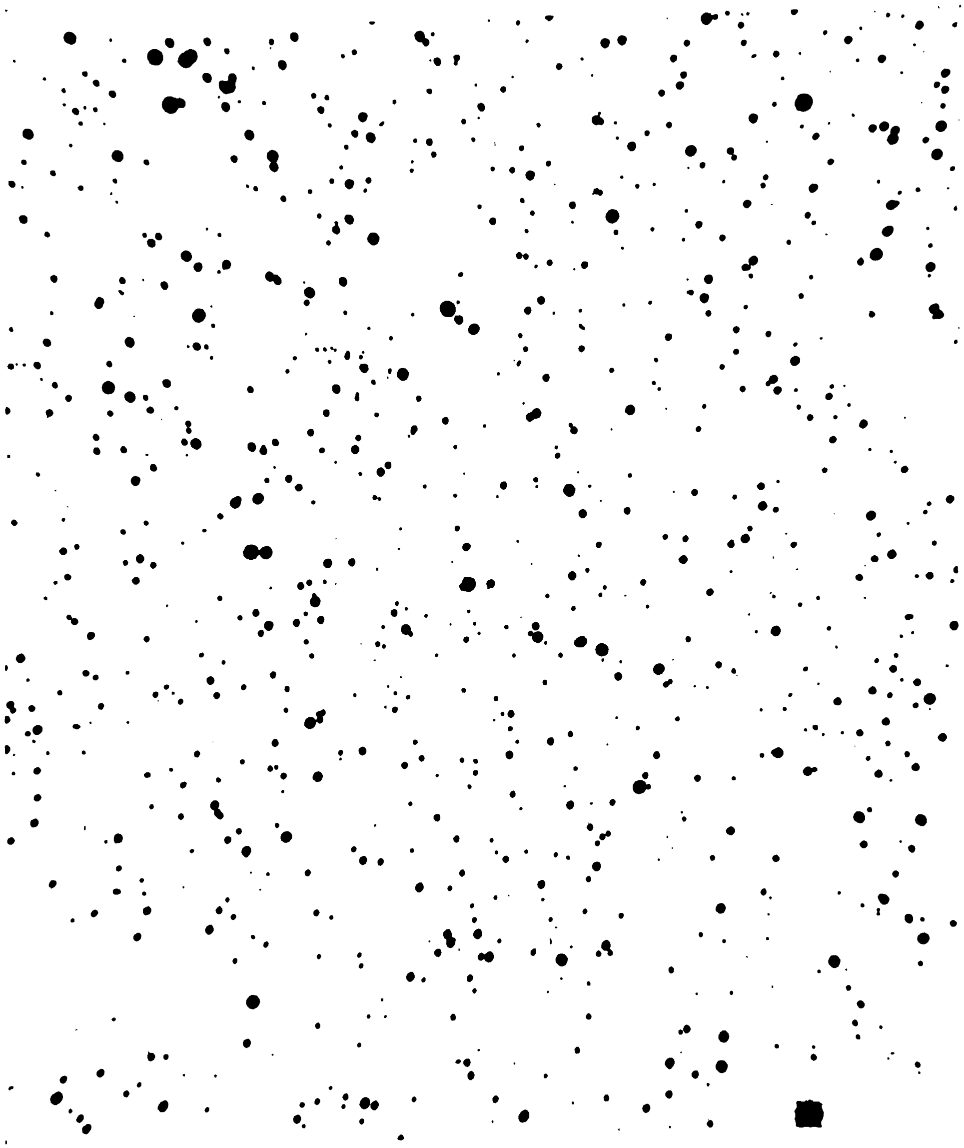
TABLE X—*Continued*

MEASURED STARS

PHOTOGRAPHIC MAGNITUDES

Hagen No.	Hagen Mag.	Photog. Mag.	Instr.	No. of Plates	p.e.	Hagen No.	Hagen Mag.	Photog. Mag.	Instr.	No. of Plates	p.e.
3...	...	6.64	C	3	0.03	58...	10.1	10.71	R	3	0.04
6...	8.3	8.67	R	3	0.02	59...	10.1	11.46	R	3	0.09
7...	8.5	8.15	C	3	0.04	60...	10.1	10.83	R	3	0.06
8...	8.6	8.6	R	1	....	62...	10.2	11.32	R	3	0.08
9...	8.6	8.51	C	3	0.05	63...	10.2	10.90	R	3	0.01
11...	8.7	9.74	R	2	....	64...	10.2	10.80	R	3	0.01
12...	8.8	10.53	R	3	0.04	65...	10.3	11.23	R	3	0.05
13...	8.8	8.95	C	3	0.04	66...	10.3	11.02	R	3	0.02
14...	8.9	8.99	R	3	0.08	67...	10.4	11.12	R	3	0.06
15...	9.0	10.11	R	2	....	68...	10.4	11.28	R	3	0.05
16...	9.0	9.66	R	5	0.08	69...	10.4	11.81	R	3	0.06
17...	9.0	9.77	R	3	0.05	70...	10.4	11.92	R	3	0.11
18...	9.0	9.33	R	3	0.05	71...	10.5	11.59	R	3	0.04
19...	9.0	10.83	R	3	0.04	72...	10.5	11.31	R	3	0.03
20...	9.1	8.95	R	3	0.03	73...	10.5	11.22	R	3	0.04
21...	9.1	10.87	R	3	0.10	74...	10.5	11.47	R	3	0.05
23...	9.1	9.72	R	3	0.06	75...	10.6	11.58	R	3	0.08
24...	9.2	9.09	R	2	....	76...	10.6	11.88	R	3	0.04
25...	9.2	9.37	R	3	0.07	79...	10.8	11.68	R	3	0.08
26...	9.2	9.37	R	3	0.04	81...	10.8	12.01	R	3	0.07
27...	9.3	10.73	R	3	0.05	82...	10.9	12.04	R	3	0.08
28...	9.3	9.46	R	3	0.04	83...	10.9	12.06	R	3	0.08
30...	9.3	9.77	R	3	0.09	84...	11.0	11.63	R	3	0.06
31...	9.4	10.05	R	3	0.04	85...	11.0	11.51	R	3	0.04
34...	9.5	9.77	R	3	0.04	86...	11.1	11.72	R	3	0.03
35...	9.5	9.91	R	3	0.11	87...	11.1	11.73	R	3	0.04
36...	9.5	9.79	R	3	0.06	88...	11.2	11.95	R	3	0.06
37...	9.5	10.00	R	2	....	89...	11.2	12.68	R	3	0.07
39...	9.6	10.39	R	2	....	90...	11.2	11.74	R	3	0.07
41...	9.7	10.41	R	3	0.02	91...	11.4	11.86	R	3	0.05
43...	9.7	10.25	R	3	0.06	95...	11.6	11.90	R	3	0.06
44...	9.7	10.67	R	2	....	96...	11.6	12.30	R	3	0.08
46...	9.8	10.44	R	3	0.08	97...	11.7	12.30	R	3	0.09
47...	9.8	10.98	R	3	0.06	98...	11.7	12.47	R	3	0.08
49...	9.9	10.76	R	3	0.04	100...	11.7	12.60	R	3	0.07
50...	9.9	10.34	R	3	0.04	101...	11.7	12.44	R	3	0.07
51...	9.9	11.16	R	3	0.06	104...	11.9	12.12	R	3	0.08
54...	10.0	11.06	R	3	0.05	106...	12.0	12.38	R	3	0.02
55...	10.1	10.62	R	3	0.07	107...	12.0	12.91	R	3	0.09
56...	10.1	10.68	R	3	0.05	108...	12.1	12.04	R	3	0.03
57...	10.1	11.19	R	3	0.07	109...	12.2	12.50	R	3	0.04
						110...	12.4	11.82	R	3	0.02

PLATE V



SPECIMEN PLATE OF THE *S Cygni* REGION, TAKEN AT THE FOCUS OF THE 24-INCH REFLECTOR OF THE YERKES OBSERVATORY

TABLE X—*Continued*

VISUAL MAGNITUDES

Hagen No.	Hagen Mag.	Magnitude	Color-Index	Spectrum Inferred	Instr.	No. of Plates	p.e.
3......	...	6.54	+0.10	A3	C	5	0.05
7......	8.5	8.33	−0.18	B7	C	3	0.04
9......	8.6	8.46	+0.05	A2	C	2	....
13......	8.8	8.71	+0.24	A6	C	1	....

TABLE XI

S CYGNI FIELD

$\alpha = 20^h3^m24^s$ $\delta = +57°41'.9$ (1900) Hagen Series VI

STANDARD STARS

B.D.		P.D.			Spectrum	Cor. for Spectrum	Photographic Magnitude
No.	Mag.	No.	Mag.	Color			
59°2137...	5.8	11107	6.26	GW−	A0	0.00	6.26
57 2084...	5.4	11100	5.28	W+	A0	0.00	5.28
56 2331...	6.3	11144	6.38	GW−	A0	0.00	6.38

MEASURED STARS

PHOTOGRAPHIC MAGNITUDES

Hagen No.	Hagen Mag.	Photog. Mag.	Instr.	No. of Plates	p.e.	Hagen No.	Hagen Mag.	Photog. Mag.	Instr.	No. of Plates	p.e.
1...	7.2	7.04	C	3	0.01	35...	9.9	11.42	R	3	0.03
2...	7.6	8.37	R	3	0.04	36...	10.0	10.61	R	3	0.12
4...	7.7	7.18	C	3	0.01	38...	10.0	11.10	R	3	0.03
6...	8.4	9.20	R	3	0.03	39...	10.1	10.72	R	3	0.12
7...	8.5	10.27	R	3	0.01	40...	10.1	11.89	R	3	0.06
8...	8.6	9.24	R	2	....	41...	10.2	11.45	R	3	0.03
9...	8.6	9.80	R	3	0.05	42...	10.2	11.66	R	3	0.02
11...	8.7	9.74	R	3	0.06	43...	10.3	11.19	R	3	0.08
12...	8.8	9.35	R	3	0.04	44...	10.3	11.78	R	3	0.08
15...	8.9	10.23	R	3	0.12	45...	10.3	11.35	R	3	0.06
16...	9.0	9.47	R	3	0.04	46...	10.3	11.44	R	3	0.04
17...	9.0	10.28	R	3	0.03	47...	10.4	10.86	R	6	0.03
18...	9.1	9.87	R	6	0.02	48...	10.4	11.21	R	3	0.07
20...	9.2	9.62	R	3	0.07	49...	10.4	12.11	R	3	0.01
22...	9.3	10.53	R	3	0.04	50...	10.5	11.43	R	3	0.05
23...	9.3	9.59	R	3	0.04	51...	10.5	11.20	R	3	0.03
24...	9.4	10.53	R	3	0.04	52...	10.5	11.76	R	3	0.03
25...	9.4	9.76	R	6	0.03	53...	10.6	11.21	R	3	0.05
26...	9.4	10.41	R	3	0.10	54...	10.6	12.04	R	3	0.07
27...	9.4	9.67	R	3	0.06	55...	10.6	11.77	R	3	0.03
28...	9.4	10.95	R	3	0.03	56...	10.6	11.29	R	3	0.03
29...	9.5	11.13	R	3	0.07	59...	10.7	11.35	R	3	0.03
30...	9.6	10.28	R	3	0.06	64...	10.9	11.95	R	3	0.05
33...	9.7	9.75	R	3	0.06	68...	11.1	11.75	R	3	0.04
34...	9.7	10.72	R	3	0.09	75...	11.4	12.19	R	3	0.08

TABLE XI—*Continued*

VISUAL MAGNITUDES

Hagen No.	Hagen Mag.	Magnitude	Color-Index	Spectrum Inferred	Instr.	No. of Plates	p.e.
1.......	7.2	7.02	+0.02	A1	C	3	0.03
2.......	7.6	7.63	+0.74	F7	C	3	0.13
4.......	7.7	7.38	−0.20	B6	C	3	0.05

TABLE XII

V DELPHINI FIELD

$\alpha = 20^h43^m14^s$ $\delta = +18°58'.0$ (1900) Hagen Series VI

STANDARD STARS

B.D.		P.D.			Spectrum	Cor. for Spectrum	Photographic Magnitude
No.	Mag.	No.	Mag.	Color			
17°4378...	6.8	11782	7.03	GW	A0	0.00	7.03
17 4431...	6.5	11903	6.98	GW	A2	0.08	7.06
15 4220...	6.0	11752	6.30	W	A0	0.00	6.30

MEASURED STARS

PHOTOGRAPHIC MAGNITUDES

Hagen No.	Hagen Mag.	Photog. Mag.	Instr.	No. of Plates	p.e.	Hagen No.	Hagen Mag.	Photog. Mag.	Instr.	No. of Plates	p.e.
2...	8.3	8.30	R	3	0.04	23...	9.9	11.04	R	3	0.06
3...	8.5	8.43	R	3	0.10	24...	10.0	10.73	R	3	0.07
4...	8.7	8.90	C	4	0.02	25...	10.1	11.21	R	3	0.06
5...	8.8	8.80	C	5	0.02	26...	10.2	11.53	R	3	0.04
6...	8.9	9.79	R	3	0.04	28...	10.3	11.53	R	3	0.65
7...	8.9	8.99	R	3	0.08	29...	10.4	11.44	R	3	0.04
8...	9.0	9.94	R	3	0.02	30...	10.5	11.30	R	3	0.03
9...	9.1	9.74	R	3	0.05	31...	10.5	11.90	R	3	0.08
10...	9.1	9.96	R	3	0.06	32...	10.5	12.01	R	3	0.11
11...	9.1	9.27	R	3	0.00	33...	10.6	11.74	R	3	0.02
12...	9.2	9.61	R	3	0.01	34...	10.6	11.24	R	3	0.11
13...	9.3	9.64	R	3	0.09	35...	10.7	11.77	R	3	0.08
14...	9.4	10.73	R	3	0.05	36...	10.7	11.34	R	3	0.03
15...	9.5	10.62	R	3	0.05	37...	10.7	11.60	R	3	0.07
16...	9.6	9.95	R	3	0.06	38...	10.7	11.19	R	3	0.04
17...	9.7	9.10	R	3	0.04	39...	10.9	11.54	R	3	0.02
18...	9.7	10.57	R	3	0.07	40...	10.9	11.65	R	3	0.03
19...	9.7	11.06	R	3	0.03	41...	10.9	11.58	R	3	0.05
21...	9.8	10.13	R	3	0.06	43...	11.0	11.56	R	2	....
22...	9.9	10.30	R	3	0.06	46...	11.1	12.07	R	3	0.03

TABLE XIII

R LACERTAE FIELD

$\alpha = 22^h38^m50^s$ $\delta = +41°50'.9$ (1900) Hagen Series III

STANDARD STARS

B.D. No.	B.D. Mag.	P.D. No.	P.D. Mag.	P.D. Color	Spectrum	Cor. for Spectrum	Photographic Magnitude
43°4298...	7.1	13348	7.18	W+	A0	0.00	7.18
40 4926...	7.0	13410	7.24	W+	A0	0.00	7.24
43 4258...	7.0	13264	7.40	GW	A0	0.00	7.40
43 4331...	6.0	13435	5.97	GW	A3	0.12	6.09
41 4619...	7.0	13387	7.45	GW−	A3	0.12	7.57
40 4866...	7.1	13258	7.76	W+	A0	0.00	7.76

MEASURED STARS

PHOTOGRAPHIC MAGNITUDES

Hagen No.	Hagen Mag.	Photog. Mag.	Instr.	No. of Plates	p.e.	Hagen No.	Hagen Mag.	Photog. Mag.	Instr.	No. of Plates	p.e.
2...	8.0	8.55	C	4	0.05	31...	10.2	12.93	R	3	0.04
5...	8.4	8.99	C	4	0.10	35...	10.5	11.52	R	3	0.03
6...	8.4	9.73	R	4	0.06	38...	10.7	11.11	R	3	0.02
7...	8.6	8.77	C	4	0.06	39...	10.8	11.04	R	3	0.04
8...	8.8	9.86	R	4	0.06	42...	11.0	11.41	R	3	0.03
9...	8.8	9.11	R	4	0.03	43...	11.1	11.22	R	3	0.08
11...	9.0	9.11	C	4	0.08	44...	11.1	12.08	R	3	0.02
12...	9.1	10.11	R	4	0.04	46...	11.1	12.00	R	3	0.05
14...	9.2	9.68	R	4	0.04	47...	11.2	11.96	R	3	0.01
15...	9.3	9.64	R	4	0.02	49...	11.2	11.76	R	3	0.02
16...	9.4	10.58	R	4	0.06	50...	11.3	11.88	R	2	....
18...	9.5	10.03	R	3	0.01	52...	11.3	12.24	R	3	0.04
19...	9.5	9.76	R	4	0.05	57...	11.5	12.13	R	3	0.04
22...	9.6	9.87	R	2	....	58...	11.5	12.10	R	2	....
23...	9.6	10.50	R	3	0.02	61...	11.6	12.57	R	3	0.02
26...	9.9	10.32	R	4	0.03	63...	11.7	11.90	R	3	0.05
28...	10.0	10.72	R	3	0.06	65...	11.8	12.08	R	3	0.02
29...	10.1	11.80	R	3	0.06	67...	12.0	13.00	R	2	....
30...	10.2	10.26	R	3	0.12	68...	12.0	12.57	R	2	....
						70...	12.2	12.64	R	3	0.05

VISUAL MAGNITUDES

Hagen No.	Hagen Mag.	Magnitude	Color-Index	Spectrum Inferred	Instr.	No. of Plates	p.e.
2.......	8.0	7.70	+0.85	F9	C	5	0.03
5.......	8.4	8.31	+0.68	F5	C	4	0.05
7.......	8.6	8.52	+0.25	A6	C	1	....

TABLE XIV

R PEGASI FIELD

$\alpha = 23^h 1^m 38^s$ $\delta = +10°0'.2$ (1900) Hagen Series II

Standard Stars

B.D. No.	B.D. Mag.	P.D. No.	P.D. Mag.	P.D. Color	Spectrum	Cor. for Spectrum	Photographic Magnitude
19°5170...	5.5	13618	5.41	GW−	A0	0.00	5.41
11 4904...	6.9	13457	6.84	GW	A2	0.08	6.92
8 4961...	4.7	13449	5.08	GW−	A0	0.00	5.08
6 5092...	7.3	13481	6.60	GW	A0	0.00	6.60
7 4991...	6.0	13643	5.39	GW	A2	0.08	5.47
6 5124...	7.5	13619	7.63	WG−	A2	0.08	7.71

Measured Stars

PHOTOGRAPHIC MAGNITUDES

Hagen No.	Hagen Mag.	Photog. Mag.	Instr.	No. of Plates	p.e.	Hagen No.	Hagen Mag.	Photog. Mag.	Instr.	No. of Plates	p.e.
1...	8.1	7.84	C	3	0.06	18...	10.5	11.64	R	3	0.06
2...	8.1	7.52	C	3	0.06	19...	10.7	12.04	R	2	.....
3...	8.4	9.36	C	1	....	20...	10.8	12.00	R	2	.....
4...	8.6	8.98	C	2	....	21...	10.9	11.77	R	2	.....
9...	9.4	10.35	R	3	0.10	22...	11.0	11.74	R	2	.....
10...	9.4	10.72	R	3	0.01	23...	11.1	12.50	R	2	.....
12...	9.8	10.59	R	3	0.06	24...	11.3	12.49	R	2	.....
13...	9.9	10.79	R	3	0.02	25...	11.3	12.12	R	2	.....
15...	10.2	11.41	R	3	0.05	26...	11.6	12.00	R	2	.....
16...	10.3	11.39	R	3	0.01	29...	11.9	12.36	R	2	.....
17...	10.4	11.48	R	3	0.05	30...	12.0	12.26	R	2	.....
						32...	12.3	12.19	R	2	.....

VISUAL MAGNITUDES

Hagen No.	Hagen Mag.	Magnitude	Color-Index	Spectrum Inferred	Instr.	No. of Plates	p.e.
1.......	8.1	7.60	+0.24	A6	C	4	0.04
2.......	8.1	7.23	+0.29	A7	C	4	0.02

TABLE XV

Y CASSIOPEIAE FIELD

$\alpha = 23^h 58^m 14^s$ $\delta = +55° 7'.5$ (1900) Hagen Series VI

Standard Stars

B.D.		P.D.			Spectrum	Cor. for Spectrum	Photographic Magnitude
No.	Mag.	No.	Mag.	Color			
56° 11...	6.7	52	6.86	W	A2	0.08	6.94
55 15...	7.4	62	7.52	W+	A0	0.00	7.52
56 31...	7.2	127	7.82	GW−	A0	0.00	7.82
56 3127...	7.4	14128	7.35	W+	A0	0.00	7.35

Measured Stars

PHOTOGRAPHIC MAGNITUDES

Hagen No.	Hagen Mag.	Photog. Mag.	Instr.	No. of Plates	p.e.	Hagen No.	Hagen Mag.	Photog. Mag.	Instr.	No. of Plates	p.e.
2...	7.5	7.97	C.R	8	0.05	22...	9.7	10.06	R	4	0.10
3...	7.9	7.21	C	3	0.02	23...	9.8	9.97	R	4	0.06
4...	8.3	8.60	C	3	0.01	24...	9.9	10.36	R	3	0.10
6...	8.6	9.98	R	4	0.06	25...	10.0	10.40	R	4	0.05
7...	8.8	9.60	R	4	0.06	26...	10.1	10.19	R	4	0.08
9...	8.9	8.94	R	4	0.05	27...	10.2	11.14	R	3	0.08
10...	9.0	9.16	R	4	0.05	28...	10.3	11.1	R	1	....
11...	9.0	8.91	R	4	0.04	29...	10.3	10.26	R	4	0.06
12...	9.0	10.49	R	3	0.05	31...	10.3	10.54	R	4	0.10
13...	9.1	9.01	R	4	0.08	33...	10.4	11.00	R	4	0.06
14...	9.2	9.37	R	4	0.08	34...	10.4	10.91	R	4	0.09
15...	9.2	9.57	R	4	0.03	36...	10.5	10.52	R	4	0.04
16...	9.4	9.70	R	4	0.09	37...	10.5	10.58	R	4	0.10
17...	9.4	10.64	R	4	0.06	38...	10.5	10.68	R	4	0.07
18...	9.5	10.45	R	4	0.07	40...	10.6	10.5	R	1	....
20...	9.6	10.61	R	4	0.08	52...	11.0	11.68	R	4	0.09
21...	9.6	9.90	R	4	0.04						

VISUAL MAGNITUDES

Hagen No.	Hagen Mag.	Magnitude	Color-Index	Spectrum Inferred	Instr.	No. of Plates	p.e.
2.......	7.5	6.88	+1.09	G5	C	3	0.03
3.......	7.9	7.35	−0.14	B8	C	3	0.02
4.......	8.3	7.94	+0.66	F5	C	3	0.03

The thanks of the author are due and are hereby most sincerely expressed to the various persons who have contributed to the progress of this work; to Professor Frost, who from the beginning showed an interest in the plan and very kindly permitted the use of the instruments necessary to the success of the undertaking; to all the members of the Observatory staff, who by their generous hospitality and help have made the time spent at the Observatory most pleasurable; to Mr. R. H. Motherwell, who made several exposures with the camera; to Mr. H. L. Alden, who assisted in a part of the reductions; and especially to Professor Parkhurst, who suggested the problem, and who, in the midst of the difficulties incident to the work, has been an inspiration not only because of the actual efforts he put forth to further the plan but also because of patience, the helpful suggestions, and the sympathetic and enthusiastic interest which he always manifested.

WILLIAMS BAY, WISCONSIN
YERKES OBSERVATORY
August 22, 1912

THE PHOTOGRAPHIC MAGNITUDE SCALE OF THE NORTH POLAR SEQUENCE[1]

By FREDERICK H. SEARES

During the past two years various investigations have been undertaken at the Mount Wilson Solar Observatory for the purpose of establishing methods of photographic photometry that may safely be employed with the 60-inch reflector. Those finally adopted involve the use of wire gauze screens and diaphragms of various apertures.

The method of diaphragms has in the past been considered questionable because of the uncertainty as to the effect of the change in the diffraction pattern. This has been investigated by two different methods and the evidence indicates that with the apertures used the diffraction effect can scarcely exceed two- or three-hundredths of a magnitude in a range of five magnitudes. The reduction constants of the diaphragms have accordingly been calculated directly from the measured areas of the apertures.

The wire gauze screen is free from difficulties arising from diffraction; but the determination of its absorption constant requires a laboratory investigation, and, without special precautions, is subject to systematic error. To obtain definite assurance of the reliability of the adopted constants, both the point and the surface absorption were measured. The point absorption was determined by means of a specially devised photometer. The surface absorption was found with the aid of an instrument of the Lummer-Brodhun type and by calculating from the measured dimensions of the mesh of the screen. The surface absorption was further controlled by the use of widely different bench lengths and by the measurement of double as well as single thicknesses of the screen. The mean result of the pieces investigated was: point absorption, 3.038 mags.; surface absorption 1.503 mags. The former differs from twice the latter by only 0.03 mag.

[1] *Contributions from the Mount Wilson Solar Observatory*, No. 70.

An objection affecting the use of both diaphragms and screens arises from the fact that the exposures of reduced intensity cannot be made simultaneously with those of full aperture. This doubles the time required for the observations and introduces errors having their origin in varying atmospheric conditions. The increased time of exposure is objectionable, but in itself does not affect the precision of the results. Changes in atmospheric transparency and steadiness are serious, though with the short exposures possible with the 60-inch reflector the chance of error is lessened, and the disturbance may be rendered accidental by increasing the number of plates. For control, the various exposures with full aperture, diaphragms, and screens are always symmetrically arranged. It is therefore possible practically to reduce the atmospheric difficulty to one of time.

The most serious difficulty encountered has been the satisfactory determination of the error depending on the distances of the stars from the axis of the instrument. It was expected that, on account of the large ratio of aperture to focal length, the corrections would be large, but that they would fluctuate from plate to plate in a most erratic manner was not foreseen. The influences of errors of focus, of the time, concentration, and temperature of development were successively studied without the discovery of any adequate explanation. With the appearance of irregularities in the error for a single plate when different directions from the axis were considered, it was suspected that temperature deformations of the mirror might be involved. A photographic record of the figure of the mirror by the knife-edge method was then made simultaneously with determinations of the distance correction. Under normal conditions it was found that the correction behaved normally; but with the greatly disturbed figure purposely produced to increase the decisiveness of the test, it became quite unmanageable.

Formerly it was not possible to cover the telescope with the canopy when the Cassegrain spectrograph was in position, and the arrangement of the program was such that the photometric observations followed those with the spectrograph. Part of the photometric plates were therefore made with the mirror in an abnormal condition, and it was these which first revealed the irregularities.

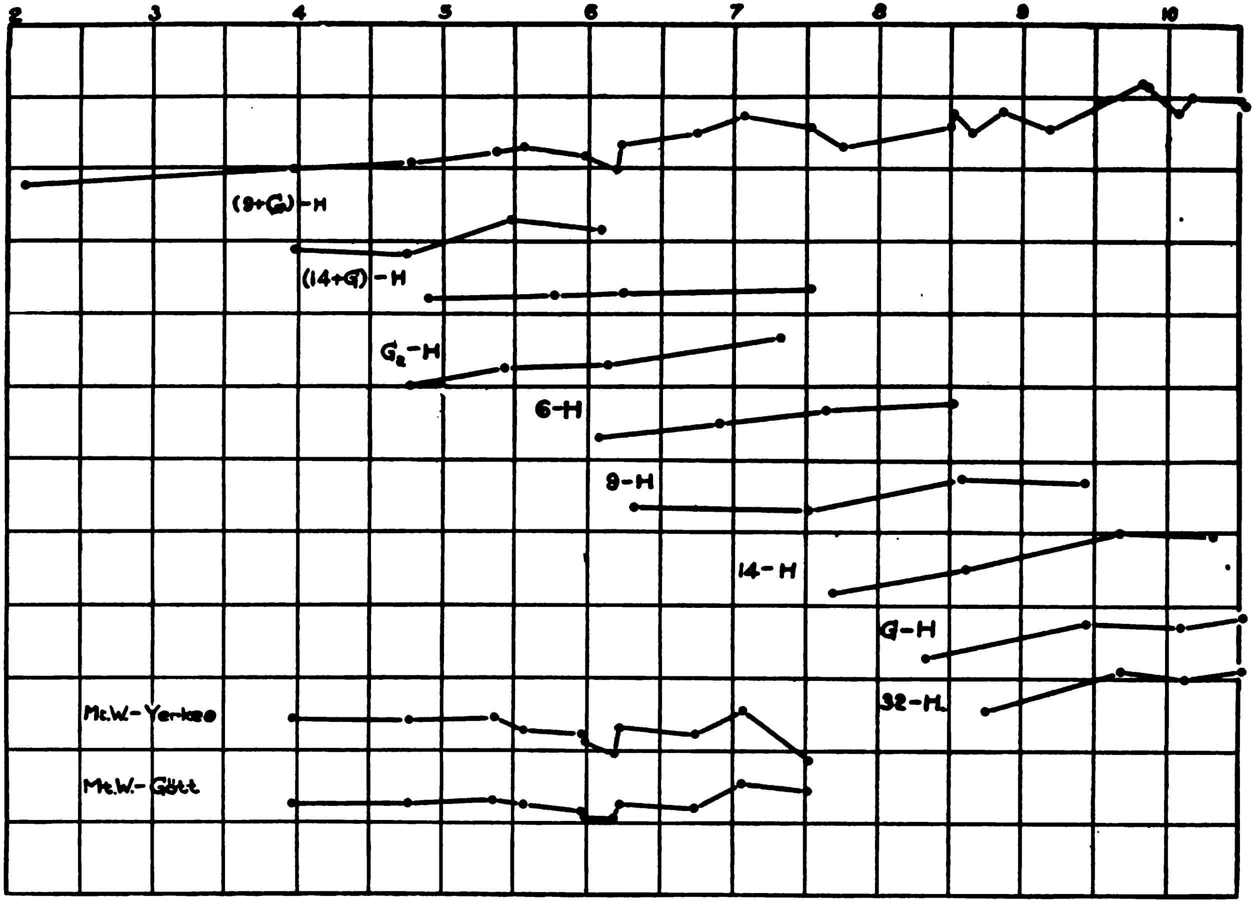


FIG. 1.—Comparison of Mount Wilson magnitudes with those of Harvard, Yerkes, and Göttingen. The first curve represents the mean values of Mt. W.—H. The curves below and to the right are the results derived from the combination of the aperture indicated with the full aperture of 60 inches. In general the ordinates are referred to the horizontal line immediately above as an axis. Vertical scale same as horizontal.

defines the inclination of the curves in Fig. 1, while the latter is the magnitude for which the scales derived by the different apertures agree with the Harvard scale. The irregularities are considerable, owing to the small number of determinations, and the inclination with respect to the axis varies from case to case. Nevertheless, the general features of the divergence are noticeable for each of the apertures 32, G, 14, 9, 6, G_2, $14+G$, and $9+G$. The intervals covered by the other determinations are too short to make them of service. The process is, in effect, an analysis of the mean curve of differences into its constituent parts, with the advantage that the inclinations of the constituent curves are not affected by the errors in the adopted reduction constants. These merely displace the separate curves in a vertical direction from their true position. The weighted mean divergence derived from the quantities in the sixth column of Table III is −0.097 mag.

The mean deviation for all the results derived with each aperture, and the corresponding mean magnitude are also appended to each of the groups in Table III. The mean deviations contain the effect of the errors in the adopted reduction constants, but it will be observed that they gradually increase with decreasing magnitude, and show a divergence of −0.069 mag. per magnitude. Were the errors of the reduction constants negligible, this quantity should equal the mean divergence of −0.097 mag. found above from the separate curves, and the difference is theoretically a measure of the effect of these errors. Actually, the influence is probably considerably less, for the values of the divergence found from the separate curves are subject to large uncertainties owing to the relatively short intervals covered. On the other hand, the uniformity with which the mean deviations for the different apertures increase with decreasing magnitude is an excellent test of the reliability of the reduction constants. Consider for example the results given by the single thickness gauze screen (G) and the 14-inch diaphragm, for which the mean magnitudes of the stars observed are practically the same. The difference in the resulting deviations is 0.06 mag. Again, for the double thickness screen (G_2), and the 14-inch diaphragm covered with a small piece of gauze ($14+G$), the difference in the mean deviations is only 0.03 mag. Incidentally, it may be

remarked that these two cases afford confirmation of the statement above concerning the freedom of the results obtained with diaphragms from any diffraction effect. With G and G_2 the central diffraction disk has the same diameter as that produced by the full aperture of 60 inches, while for 14 and $14+G$ it is four times as large. In one case the diaphragm results give the larger deviation, in the other, the smaller.

It appears, therefore, that whether we consider each aperture by itself, or the mean deviations as a group, we arrive at substantially the same result; and it is equally clear that errors in the reduction constants cannot have played any important part in producing the divergence between the Mount Wilson results and those of Harvard.

Finally, a word may be said with regard to the comparisons with Parkhurst and Schwarzschild, which are also shown graphically in Fig. 1. If the last, and apparently discordant, difference with Parkhurst be disregarded, there is little to be remarked in the way of divergence between Mount Wilson and Yerkes. Such as there is appears to be in a direction opposite to that given by the comparison with Harvard. With Göttingen, on the other hand, there is no positive evidence of a progressive difference. The constant difference of 0.37 mag. shown by both comparisons is due to the fact that Parkhurst and Schwarzschild have chosen their zero points to agree with the Harvard scale at the sixth magnitude, while for the preliminary Mount Wilson values the coincidence is between 10.5 and 15.5. The results may be reduced to the international standard by adding +0.37 mag. to the Mount Wilson magnitudes and to the ordinates of the various curves. The appearance of similar irregularities in the three series of differences, which is well shown in the figure, merely indicates that the Mount Wilson values for the individual stars are affected to a considerable extent by accidental errors. This is especially noticeable in the case of star *1r* for which the Mount Wilson value, in spite of the considerable number of determinations, is probably abnormal. This object has been excluded from the means in Table III.

Since the Harvard magnitudes for the faint stars have been used for the derivation of the Mount Wilson results, it follows that

the application of the homogeneity test to the Harvard scale is in reality a comparison of Harvard magnitudes for bright stars with Harvard results for faint stars, the only intermediate step being the interposition of a screen or diaphragm for the purpose of giving the brighter objects an apparent magnitude comparable with the real brightness of the fainter stars. Only two conclusions seem possible: either the methods used for the derivation of the Mount Wilson magnitudes are subject to errors whose presence, upon a priori grounds, would not have been suspected, or else the Harvard scale is not wholly consistent.

The preceding paragraphs present the results from the standpoint of the principles that formed the basis of the observational program. The purpose was to obtain a scale for the brighter stars which should be homogeneous with an adopted series of magnitudes for the fainter objects, and to this end the scale for the faint stars was introduced as an essential factor into the investigation. The reduction constants also enter into the final results, but in such a way as to produce a partial neutralization of their errors. It is important to note, however, that the slope of the scale derived by any given combination of screens and diaphragms is quite independent of these errors.

It is possible, however, to analyze the data from an entirely different point of view, for they afford material for a series of scale determinations for the brighter stars which individually are independent of the magnitudes assumed for the fainter objects. The scale to be established is thus made to depend wholly upon the constants of the diaphragms and screens, the assumed magnitudes being used only to fix the zero point. That such an arrangement is possible follows from the fact that each bright star has been reduced to several different apparent magnitudes. Consequently, for a considerable number of bright stars there are values derived from approximately the same apparent magnitude, say the twelfth, and the collection of all such results gives at once a scale of the character described. The stars of the twelfth magnitude determine the zero point, but the scale depends entirely upon the diaphragms and screens used.

From this standpoint, therefore, the results are not merely an

extension of the scale assumed for the faint stars, but an essentially independent determination. The final mean result must obviously be the same as that already given, for it involves only a rearrangement of the data; but the analysis is of importance, for since each of the constituent scales thus derived is obtained by a comparison with faint stars of the same brightness, their individual slopes will be free from any influence depending on the apparent magnitude to which the bright stars were reduced. This is not true of the separate scales given above, and a comparison of the two series of results should bring to light any such influence.

This rearrangement of the material is shown in Table IV. As previously explained, the apparent magnitudes used for the derivation of the results in Table II may be found by adding to the mean magnitudes in the second column the approximate values of the reduction constants given in the table heading. These were formed and arranged in order of increasing values. Opposite each were written the corresponding star number, the mean Mount Wilson magnitude, the aperture used, and the deviation for that aperture given in the body of Table II. The resulting list was divided into seven parts, each of which, excepting the first and the last, includes a range in apparent magnitude of 0.4 mag. The quantities within each of the groups were then arranged in the order of decreasing brightness of the stars included. The results are those shown in Table IV. The significance, therefore, of any one of the groups of this table, say the second, is that the stars whose numbers and mean magnitudes appear in the second and third columns were reduced to apparent magnitudes lying between 10.8 and 11.2 by means of the diaphragms and screens listed in the fourth column. The comparison of the reduced images with faint stars of the same magnitude gave values for the actual brightness differing from the mean magnitudes by the amounts shown in the last column. As before, the unit in which the deviations are expressed is 0.01 mag., and the quantities in parentheses represent the number of determinations upon which each deviation depends.

If, therefore, to the mean magnitudes in the third column there be added the deviations in the last column, we shall have a scale whose slope is independent of the assumed scale for the faint stars

TABLE IV

DEVIATIONS ARRANGED ACCORDING TO APPARENT MAGNITUDE

Apparent Magnitude	Star	Mean Mt. W. Mag.	Aperture	Deviation
9.9–10.6.......	1	3.97	14+*G*	+18 (1)
	2*s*	5.97	9	+10 (1)
	3*s*	6.21	9	− 2 (1)
	6	6.74	9	−10 (1)
	2*r*	7.52	14	−14 (1)
	2*r*	7.52	*G*	−20 (1)
	3*r*	8.51	32	+13 (1)
	10	8.65	32	−22 (2)
			Mean........	− 5 (9)
10.8–11.2......	1	3.97	9+*G*	− 6 (3)
	2	4.78	14+*G*	+ 2 (9)
	2	4.78	G_2	− 1 (5)
	2*s*	5.97	6	− 6 (3)
	5	5.99	6	+10 (3)
	5	5.99	32+*G*	−13 (2)
	1*r*	6.19	6	− 2 (4)
	3*s*	6.21	6	+ 3 (4)
	3*s*	6.21	32+*G*	− 9 (1)
	7	7.06	9	− 4 ( )
	8	7.78	14	− 8 (3)
	4*r*	8.87	32	− 4 (4)
	11	9.19	32	− 7 (3)
	6*r*	10.07	40	− 4 (3)
			Mean........	− 2 (49)
11.3–11.7......	1*s*	2.10	*G*+G_2	+ 2 (3)
	1*s*	2.10	14+2*G*	− 3 (4)
	3	5.36	14+*G*	+ 5 (7)
	3	5.36	G_2	− 3 (7)
	4	5.56	14+*G*	+ 6 (6)
	4	5.56	G_2	+ 3 (5)
	6	6.74	6	−13 (3)
	2*r*	7.52	9	−27 (1)
	8	7.78	9	− 6 (4)
	9	8.50	14	− 4 (4)
	9	8.50	*G*	−12 (2)
	3*r*	8.51	14	− 7 (2)
	3*r*	8.51	*G*	−24 (1)
	10	8.65	14	+ 2 (3)
	13	10.17	40	−31 (1)
	14	10.51	40	+ 5 (2)
	7*r*	10.54	40	− 4 (2)
			Mean........	− 2 (57)
11.8–12.2......	1*s*	2.10	9+2*G*	+ 3 (7)
	1	3.97	6+*G*	+ 4 (3)
	2	4.76	9+*G*	−10 (2)
	2*s*	5.97	14+*G*	− 1 (6)
	2*s*	5.97	G_2	+ 1 (7)

TABLE IV—*Continued*

Apparent Magnitude	Star	Mean Mt. W. Mag.	Aperture	Deviation
11.8–12.2......	5	5.99	G_2	0 (3)
	5	5.99	$14+G$	− 3 (4)
	1r	6.19	$14+G$	0 (9)
	3s	6.21	$14+G$	− 2 (4)
	7	7.06	6	+ 5 (2)
	7	7.06	$32+G$	+ 7 (1)
	10	8.65	G	−17 (1)
	4r	8.87	14	−15 (2)
	11	9.19	14	+ 3 (3)
	12	9.83	32	+10 (4)
	5r	9.86	32	+ 7 (4)
	6r	10.07	32	+ 7 (3)
	13	10.17	32	+ 2 (3)
			Mean........	+ 1 (68)
12.3–12.7......	3	5.38	$9+G$	0 (4)
	4	5.56	$9+G$	− 2 (5)
	1r	6.19	G_2	+ 7 (6)
	3s	6.21	G_2	+18 (3)
	6	6.74	$14+G$	+ 6 (2)
	2r	7.52	6	+ 5 (3)
	2r	7.52	$32+G$	+15 (5)
	8	7.78	6	+18 (3)
	9	8.50	9	+ 3 (5)
	3r	8.51	9	+ 6 (3)
	10	8.65	9	+15 (2)
	11	9.19	G	+ 1 (3)
	14	10.51	32	+11 (3)
	7r	10.54	32	+ 4 (2)
			Mean........	+ 7 (49)
12.8–13.2......	1s	2.10	$6+2G$	− 3 (4)
	1	3.97	$14+2G$	+ 7 (2)
	2s	5.97	$9+G$	+ 4 (3)
	5	5.99	$9+G$	+ 1 (2)
	1r	6.19	$9+G$	−11 (4)
	3s	6.21	$9+G$	−11 (4)
	6	6.74	G_2	+18 (2)
	7	7.06	$14+G$	− 6 (2)
	7	7.06	G_2	+ 2 (2)
	4r	8.87	9	− 5 (2)
	11	9.19	9	+ 4 (3)
	12	9.83	14	0 (4)
	12	9.83	G	+ 3 (1)
	5r	9.86	14	− 4 (4)
	5r	9.86	G	−11 (1)
	6r	10.07	14	0 (2)
	6r	10.07	G	− 4 (2)
	13	10.17	14	+19 (2)
			Mean........	− 1 (46)

TABLE IV—*Continued*

Apparent Magnitude	Star	Mean Mt. W. Mag.	Aperture	Deviation
13.3–13.9......	3	5.36	6+*G*	− 8 (2)
	4	5.56	6+*G*	−16 (3)
	2r	7.52	14+*G*	− 7 (3)
	8	7.78	14+*G*	−10 (4)
	8	7.78	G_2	+ 8 (4)
	9	8.50	6	+ 6 (4)
	3r	8.51	6	+ 3 (2)
	10	8.65	6	+22 (1)
	4r	8.87	32+*G*	+13 (4)
	12	9.83	9	−20 (2)
	13	10.17	*G*	−15 (1)
	14	10.51	14	− 6 (3)
	14	10.51	*G*	−13 (2)
	7r	10.54	14	−11 (1)
	7r	10.54	*G*	+10 (1)
			Mean........	− 2 (37)

and depends only upon the constants of the screens and diaphragms used. The magnitudes of the faint stars have been used only to fix the zero point.

An examination of the deviations in the last column of Table IV shows at a glance that each of the seven scales is practically identical with the mean scale. There are irregularities, noticeable in the first group, caused by the small number of observations, and there are obviously constant systematic differences, but in no instance is there a progression in the deviations which would indicate an appreciable divergence of the separate scales from the mean. In other words, we arrive at the same result whether we use a single diaphragm and reduce the bright stars successively to different apparent magnitudes, or whether we use a series of different diaphragms and reduce them to the same apparent magnitude. Apparently there is no appreciable dependence of the slope of the scale upon the magnitudes to which the bright stars were reduced.

There is a point of interest relating to the systematic differences appearing in the deviations for the different groups which were referred to in the preceding paragraph. An important feature of the original reduction was the derivation of scales for the bright stars which should be homogeneous with the adopted scale for the fainter objects. The homogeneity obtained obviously refers not

merely to the general slope, but includes as well the irregularities of the assumed scale. But the scales actually found by the different combinations overlap in such a way as to produce at least a partial elimination of these irregularities, for each of the final magnitudes depends upon several faint stars differing considerably in brightness. The mean scale, therefore, should not only agree in slope with the assumed scale for the faint stars, but should be relatively free from any irregularities affecting the latter.

Turning again to the scales of Table IV, and noting that for each the magnitudes have all been determined by a comparison with a group of faint stars having approximately the same brightness, it appears that any irregularity in the scale for the faint stars will enter as a constant error. In other words, the zero point will not have been correctly determined, and this fact will reveal itself through the appearance of a constant systematic difference when a comparison is made with the mean scale, for, as has just been shown, the latter should be relatively free from irregularities.

TABLE V

IRREGULARITIES OF SCALE FOR FAINT STARS

Average Mag.	Average Deviations		No. Determinations
	I	II	
10.2	$-0^m.05$	$-0^m.05$	9
11.0	− .02	− .03	49
11.5	− .02	− .02	57
12.0	+ .01	.00	68
12.5	+ .07	+ .07	49
13.0	− .01	+ .02	46
13.6	−0.02	−0.02	37

The average differences appended to the groups of Table IV, and collected in the second column of Table V, are therefore the relative errors of the zero points of the seven scales, and are to be interpreted as a measure of the deviations from uniformity in the scale for the faint stars.

Disregarding the first, which is of low weight, it is seen that the differences are all small, excepting that for magnitude 12.5. Here there seems to be an irregularity of appreciable amount. With

this exception, the internal consistency of the scale for the faint stars must be regarded as very satisfactory.

It is of interest to note that the result is largely independent of residual irregularities in the mean scale for the bright stars, due either to an imperfect elimination of any non-uniformity in the scale for the fainter objects, or to the uncertainties in the reduction constants for the screens and diaphragms. Broadly speaking, each of the scales of Table IV covers the entire range of the mean scale for the bright stars. Irregularities in the latter would therefore enter into all of the comparisons and affect by a constant amount the average deviations of Table V, so that the relative values would not be influenced thereby. The validity of this statement is easily tested, at least in so far as uncertainties in the reduction constants are concerned. As previously remarked, the average deviations in the last line of Table II do not, strictly speaking, represent the errors of the constants; but for a moment we may consider that such is rigorously the case. If, therefore, each of the deviations of Table II be corrected by the amount of the systematic deviation at the bottom of the column in which it stands, and if the results of Table V be revised accordingly, we shall obtain differences which are free from the errors of the reduction constants. The results of such a revision are given in the third column of the table. In only one case do these differ from those previously found by more than 0.01 mag. Finally, it may be remarked that the absence of any general progression in the differences of Table V is again an indication that the scales for bright and faint stars have sensibly the same slope.

There remains still to be effected a comparison of the scales of Table IV with that of Harvard. This is accomplished by adding to the mean magnitudes in Table IV the corresponding deviations in the last column and comparing the results with the Harvard magnitudes, or more directly, by adding the deviations of Table IV to the differences Mt. W.−H. in Table II. The weighted mean results for groups of stars are given in the third and fourth columns of Table VI. The stars included in each group are indicated in the second column, and the apparent magnitude to which they were reduced for comparison with faint stars in the first column. The

comparisons are shown graphically in Fig. 2. The divergence revealed by the original reduction appears in all cases excepting the

TABLE VI

COMPARISON OF INDEPENDENT SCALE DETERMINATIONS WITH THE HARVARD SCALE

Apparent Magnitude	Stars	Means		No. Det.	Dev. for 1 Mag.
		Mag.	Mt. W.−H.		
9.9–10.6	1, 2s	4.97	−32	2	$0^m.000$
	3s, 6	6.48	−34	2	
	2r	7.52	−38	2	
	3r, 10	8.60	−30	3	
10.8–11.2	1	3.97	−56	3	
	2	4.78	−47	14	−0.071
	2s, 5, 3s	6.07	−38	13	
	7, 8	7.49	−30	5	
	4r, 11, 6r	9.33	−19	10	
11.3–11.7	1s	2.10	−62	7	−0.065
	3, 4	5.45	−34	25	
	6, 2r, 8	7.36	−39	8	
	9, 3r, 10	8.54	−25	12	
	13, 14, 7r	10.45	− 7	5	
11.8–12.2	1s	2.10	−58	7	−0.068
	1, 2	4.29	−51	5	
	2s, 5, 3s, 7	6.13	−36	27	
	10, 4r, 11	8.99	−25	6	
	12, 5r, 6r, 13	9.96	+10	14	
12.3–12.7	3, 4	5.48	−37	9	−0.071
	3s, 6	6.42	−16	6	
	2r, 8	7.59	−11	11	
	9, 3r, 10, 11	8.68	−14	13	
	14, 7r	10.52	+ 6	5	
12.8–13.2	1s, 1	2.72	−57	6	−0.080
	2s, 5, 3s	6.08	−40	9	
	6, 7	6.95	−11	6	
	4r, 11, 12	9.45	− 3	10	
	5r, 6r, 13	9.99	0	11	
13.3–13.9	3, 4	5.48	−49	5	−0.085
	2r, 8	7.71	−32	11	
	9, 3r, 10, 4r	8.65	− 6	11	
	12, 13	9.94	−12	3	
	14, 7r	10.52	− 8	7	

first, and here the absence of the typical slope is probably due to the small number of determinations and a chance combination of large errors of observation. The divergence per magnitude for each of

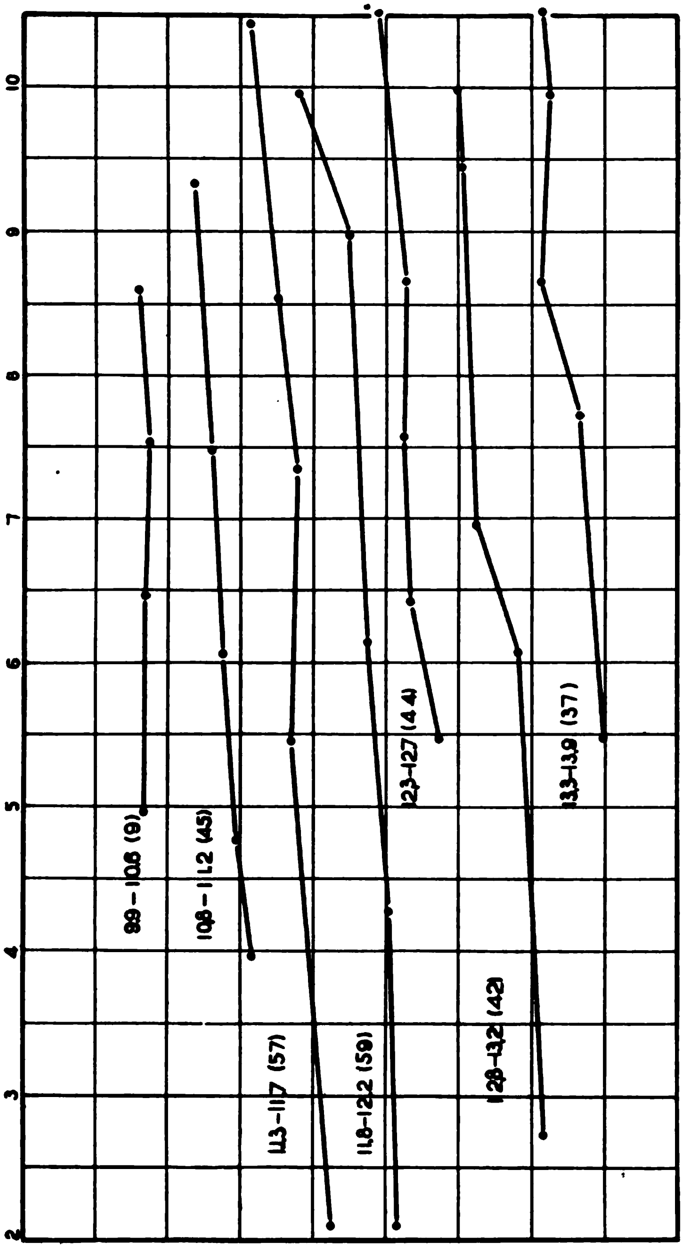


FIG. 2.—Comparison with Harvard (Mt. W.—H.) of separate scales derived by reducing bright stars to different apparent magnitudes. The limiting range of apparent magnitude and the number of observations are indicated at the left. The axis for each curve is the horizontal line immediately above. Vertical scale same as horizontal.

the scales is given in the last column of Table VI. Omitting the first, they show a high degree of accordance, and merely confirm the result previously found.

In addition to the results already described, the following may be mentioned as bearing upon the question of the scale for the brighter stars. Although these objects are in general so scattered that each has been separately compared by successive exposures with the faint stars surrounding the Pole, there are three, Nos. 1*s*, 5, and 8, sufficiently close to each other to permit of their being photographed with a single exposure. These have been directly intercompared by means of a series of diaphragm exposures. The results are summarized in Table VII. Plate 764, for example, was

TABLE VII

RELATIVE MAGNITUDES OF STARS 1*s*, 5, AND 8

Plate No.	Apertures	Exposure Time	Stars 1*s* and 5		Stars 1*s* and 8	
			Δm	Wt.	Δm	Wt.
P763....	14, 9, 6, 14+*G*, 9+*G*, 6+*G*	10^s	....	..	5.73	1
764....	14, 9, 6, 14+*G*, 9+*G*, 6+*G*	10, 30, 60	4.03	8	5.64	3
798....	14, 9, 6, 14+*G*, 9+*G*, 6+*G*	10, 30, 60	....	..	5.58	4
800....	32, 32+*G*, 32+G_2........	10, 30	3.86	4	5.95	2
Mean Δm..............................			3.97	..	5.69	..
Δm from Table II........................			3.89	..	5.68	..
Δm from *H.C.*, 170......................			3.68	..	5.39	..

given three series of exposures of 10, 30, and 60 seconds, respectively. The apertures for each series were 14, 9, 6, 14+*G*, 9+*G*, and 6+*G*, having reduction constants of approximately 3, 4, 5, 6, 7, and 8 magnitudes. The images of any star for any series establish a scale which may be used for the determination of the relative brightness of the other two stars, the images for the latter being chosen from the same series. The resulting differences in magnitude for stars 1*s* and 5, and 1*s* and 8 are in the fourth and sixth columns of the table. Their means are 3.97 and 5.69 mags., respectively, while the corresponding differences from Table II are 3.89 and 5.68. The results, as far as the scale is concerned, are the same as before. The determination is of course not independent, for the same methods have been used for the reduction of the

light by a known amount as before. But the observations and reductions are quite different, and the results do not depend upon an intermediate comparison with the faint stars.

SUMMARY

1. The photographic magnitudes of the bright stars of the Polar Sequence have been determined by comparison with the stars included between 10.5 and 15.5. The reduction in the light was produced by combinations of screens and diaphragms whose absorption constants range from one to eleven magnitudes. The Harvard magnitudes for the faint stars, which agree closely with an independent determination, were used for the comparison. The methods employed should give a mean scale which is nearly homogeneous with that of the faint stars. Various tests indicate that this result has been realized with a reasonable approximation, and that the errors in the reduction constants affect the scale only to a minor degree.

2. Although the original program and the reduction involve merely an extension of the scale for the faint stars to include the brighter objects, it is possible to analyze the results into a series of separate and independent determinations. The zero points are fixed by comparison with groups of faint stars, but the slope depends wholly upon the reduction constants of the screens and diaphragms. The individual results are in close agreement with the mean scale.

3. A direct intercomparison of *Polaris* and two other bright stars having magnitudes 5.99 and 7.78, respectively, gave differences in brightness which are practically identical with those resulting from the mean scale.

4. An examination of the internal consistency of the Harvard scale for the faint stars from magnitude 9.9 to 13.7 reveals only minute deviations from uniformity.

5. A comparison of the mean scale for the bright stars with the corresponding Harvard magnitudes shows a clearly marked divergence, nearly linear in character, and approximately represented by the formula

$$\text{Mt. W.}-\text{H.} = -0^{\text{m}}070(11^{\text{m}}.0-M),$$

which is valid for values of M from 2 to 9. The observed differences are zero at the tenth magnitude.

6. If the Mount Wilson magnitudes for the faint stars be included in the comparison, and if the results be referred to the international zero point, the differences from magnitudes 2 to 15.5 are expressed by

$$\text{Mt. W.}-\text{H.}=+0^{m}37-0^{m}070(11.0-M)$$

in which the second term is to be disregarded for $M>10$.

7. A comparison of the mean scale with the determinations of Schwarzschild and Parkhurst, which extend from magnitudes 4.0 to 7.5, gives sensibly constant differences which become zero when the Mount Wilson magnitudes are referred to the international zero point.

Mount Wilson Solar Observatory
February 27, 1913

DETERMINATION OF PERIODICITIES BY THE HARMONIC ANALYZER WITH AN APPLICATION TO THE SUN-SPOT CYCLE

By A. A. MICHELSON

It has been shown[1] that the values of the coefficients of a Fourier series may be obtained by a mechanical integration, with great facility and with considerable accuracy by the harmonic analyzer.

For this purpose the given function is copied on the machine, which then draws a curve whose ordinates at given distances along the axis of abscissas are proportional to the coefficients of the corresponding Fourier series.

The machine gives $C=\Sigma f(n)\cos n\theta$ or $S=\Sigma f(n)\sin n\theta$ which summations approximate to the corresponding integrals as the number of elements, m (in this case 80) increases.

Putting $\frac{m}{\pi}\theta=k$, the Fourier integrals are

$$C=\int_0^k f(x)\cos kx\,dx$$

$$S=\int_0^k f(x)\sin kx\,dx\,.$$

If the function to be investigated is periodic

$$f(x)=\Sigma a_n\cos(nx-\phi_n),$$

which gives

$$C_n=\frac{a_n}{\omega}[\cos\phi\sin\omega-\sin\phi(1-\cos\omega)]$$

$$S_n=\frac{a_n}{\omega}[\sin\phi\sin\omega+\cos\phi(1-\cos\omega)]$$

where $\omega=(k\pm n)h$.

In the Fourier integral h is infinite, and C and S are negligible except for $k=\pm n$.

[1] A. A. Michelson and S. W. Stratton, "A New Harmonic Analyzer," *Am. Jour. Sci.*, (4) 5, 1, 1898.

The intensity of the "periodogram"[1] is $I=C^2+S^2$ which gives in the present instance $I_n=a_n^2\,\dfrac{\sin^2\frac{\omega}{2}}{\left(\frac{\omega}{2}\right)^2}$ which has its maximum value a_n^2 at $\omega=0$. The frequency is the value of k at this point. The

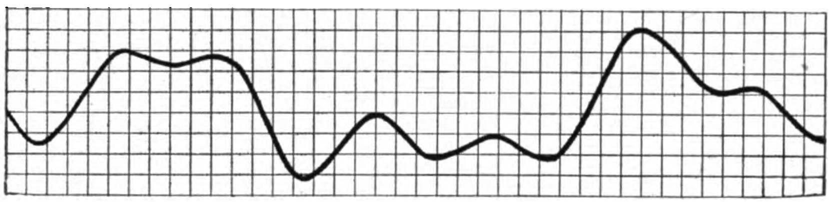


FIG. 1

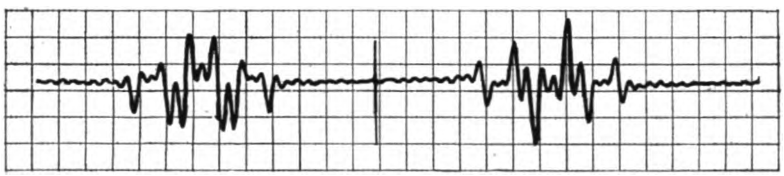


FIG. 2

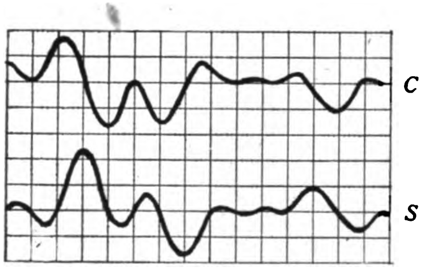


FIG. 3

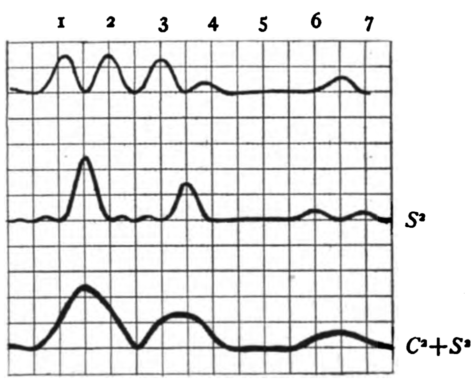


FIG. 4

maximum value of the curve given by the harmonic analyzer is therefore proportional to the amplitude a_n of the corresponding simple harmonic element of the function.

[1] Arthur Schuster, "The Periodogram and Its Optical Analogy," *Proc. Royal Society*, 77, 136, 1906.

The phase is also given by $\tan \phi_n = \frac{S_n}{C_n}$ at this point.

A test of the performance of the machine was made in the analysis of the function Y whose graph is given in Fig. 1.

The C and S curves are given in Fig. 2, and the same on a larger scale, together with C^2, S^2, and C^2+S^2 in Figs. 3 and 4.

From these we find the values given in the second column, while the first gives the elements from which Y was constructed. The agreement is quite as good as could be expected.

$$\begin{array}{ll} Y=-3.0\cos(1.5x-.5\pi) & Y=-2.9\cos(1.5x-.45\pi) \\ \quad +2.0\cos(3.5x-.5\pi) & \quad +2.0\cos(3.4x-.40\pi) \\ \quad +1.2\cos(6.3x \qquad) & \quad +1.3\cos(6.4x-.05\pi) \end{array}$$

It may be noted that the method fails, and for the same reason as in the "spectroscopic" method, when the components are too close together. In fact the "limit of resolution" is the reciprocal of double the number of periods N over which the integration extends. Thus if there are two components of 9.5 and 10 periods respectively in this distance, the limit of resolution $\frac{\delta T}{T} = \frac{1}{20} = \frac{1}{2N}$, and the two components are distinctly resolved.

A similar limitation occurs when there is but one period or less in the total length—for then the two values corresponding to $k = \pm n$ partially overlap.

A similar treatment of the sun-spot curve, as furnished in the interesting paper of H. Kimura[1] gave the following results:

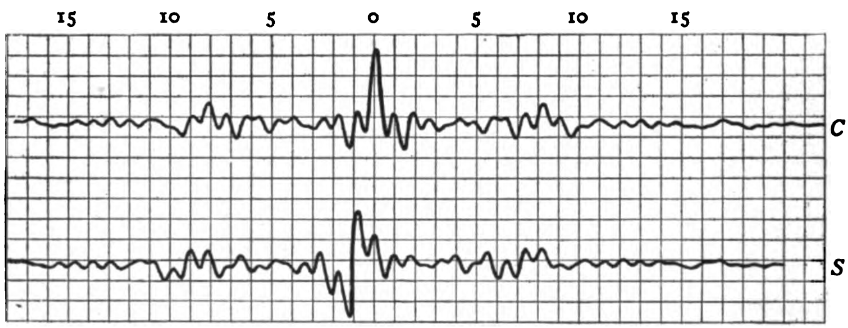


FIG. 5 N divs. $= \frac{80}{N}$ yrs.

[1] *Monthly Notices, R.A.S.*, 73, 543, May 1913.

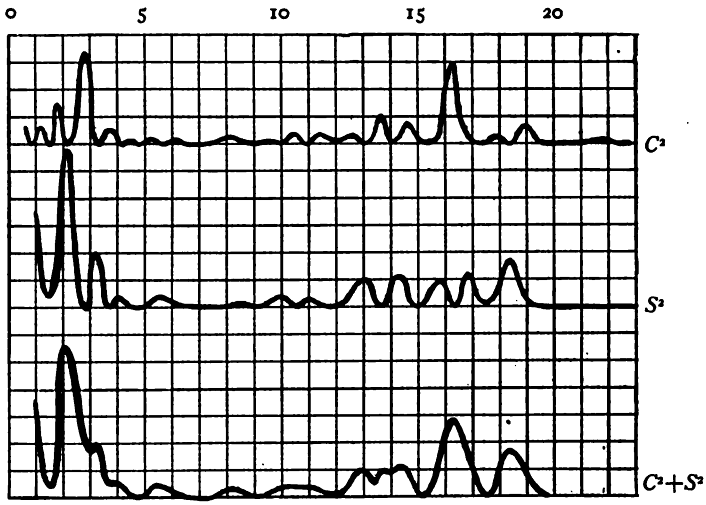


FIG. 6 N divs. $= \frac{160}{N}$ yrs.

The curve was first taken from 1750 to 1850 and furnished the C and S curves given in Fig. 5. From these the "intensity" curve C^2+S^2 was found and reproduced in Fig. 6.

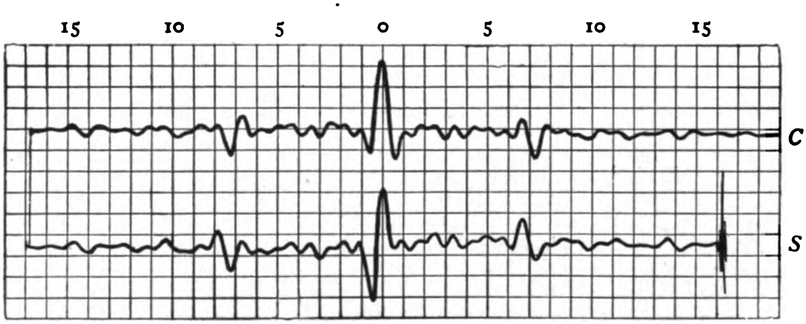


FIG. 7 N divs. $= \frac{80}{N}$ yrs.

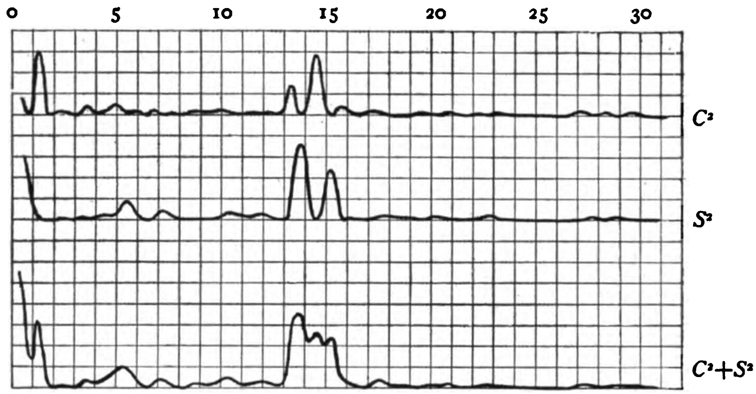


FIG. 8 N divs. $= \frac{160}{N}$ yrs.

FIG. 9 N divs. $= \frac{128}{N}$ yrs.

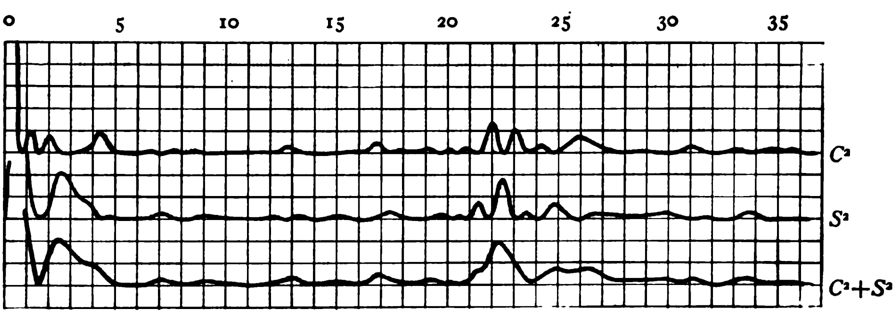


FIG. 10 N divs. $= \frac{256}{N}$ yrs.

A similar treatment of the interval from 1800 to 1900 gave Figs. 7 and 8, while the entire curve from 1750 to 1910 furnished results given in Figs. 9 and 10.

The periods and amplitudes deduced from these curves are given in the following table:

1750 to 1850		1800 to 1900		1750 to 1910	
Period	Amplitude	Period	Amplitude	Period	Amplitude
80 yrs.	5.3	129 yrs.	3.9	105 yrs.	3.5
50 "	2.0	44 "	1.4	58 "	2.2
40 "	1.4	30 "	2.2	36 "	1.3
29 "	1.6	22 "	1.4	28.5 "	1.0
19.5 "	1.2	18.2 "	1.0	19.9 "	1.3
15.7 "	1.4	15.4 "	1.6	15.1 "	1.5
14.5 "	1.4	13.3 "	1.1	13.3 "	1.3
12.5 "	2.2	11.6 "	4.2	11.4 "	2.9
11.2 "	2.4	11.0 "	3.6	10.3 "	1.8
9.9 "	3.8	10.5 "	3.5	8.6 "	1.8
8.7 "	2.9	9.1 "	1.4	8.3 "	1.6

It appears on inspection of these tables that there is but little relationship between the two parts of the sun-spot record, notwithstanding the fact that one-half is common to both—except for the 11-year period; and even here this result in the first case is quite dubious, while in the second it is much more probable that there are three periods (of 11.6, 11.0, and 10.5). The third or complete 160-year record shows a fairly isolated period of 11.4 years.

The given curves do not extend beyond the 6-year period, but in another case they have been extended to something less than the 3-year period with no certain indications of anything like a component having a period of 8.36 years, or of 4.79 years as found by Schuster.

Indeed it would seem that with the exception of the 11-year period and possibly a very long period (of the order of 100 years), the many periods found by previous investigators are illusory.

It will probably be found that even the 11-year period is in fact not constant, but is subject to secular change; in which case the sun-spot curve should be represented, not by a summation of homogeneous elements, but by an expresson of the form $Y=\psi(t)\cos[nt+\phi(t)]$.

NOTE

In a recent paper, C. V. Burton[1] suggests a method not essentially different from that given by Lord Rayleigh[2] for the resolution of a function by the diffraction of light by means of a screen whose apertures permit light to pass whose amplitude is proportional to the function to be analyzed.

It can readily be shown that the resolution can also be effected by a diffraction grating whose errors of spacing are proportional to the function—provided these errors are not too large compared with the average grating space. The periodicities in the function will be presented in the form of "ghosts" about the principal spectral line.

[1] *Proc. Phys. Soc.*, June 1913.

[2] *Phil. Mag.*, (6) **5**, 238, 1903.

A PROBABLE PARALLAX OF THE NORTH AMERICA NEBULA

By E. BUCH ANDERSEN

Till now it has been possible only in a few cases to determine parallaxes of nebulae in a direct way and only for those nebulae which have been proved to be in physical connection with one or more fixed stars. All that can be said with any certainty is that the gaseous nebulae in general do not differ from the fixed stars in regard to either proper motion or radial velocity, so that gradually it has come to be regarded as probable that most of the gaseous nebulae belong to our stellar system. Apart from the ordinary physical connection between nebulae and stars, of which several examples have been noticed (*Pleiades* nebulae, *Orion* nebula, the annular nebula in *Lyra*, etc.), the vast irregular gaseous nebulae often seem to have a peculiar influence on the stars in their vicinity; their density may suddenly decrease to such a degree that it looks as if the nebula were placed in a dark hole. As characteristic examples may be mentioned: *Orion* nebula, nebula about ρ *Ophiuchi*, ξ *Persei*, North America nebula, γ *Scuti*, 15 *Monocerotis*, and several others.[1] It is a curious fact that all these objects are found in regions very rich in stars (with the exception of the *Orion* nebula all are in the Milky Way itself); perhaps it is accidental, because the phenomena can be observed only in places where the star-density is great; or perhaps it is the real distribution and another proof that these nebulae belong to the stellar system. Such dark regions may also be found without apparently containing any nebula (e.g., near α *Cephei*, δ *Ophiuchi*, η *Carinae*, etc.), which, however, are in the Milky Way.

As to the real cause of these "rifts" there are various opinions, two of which have held their own. According to the first the nebula has moved and in some way absorbed or destroyed the stars which it met on its way, so that the "rift" must be considered as a tube or a canal, through which the nebula has passed. The other explanation is that the luminous nebula is sometimes surrounded

[1] See, e.g., *Astrophysical Journal*, 31, 8, 1910.

by a dark nebula or accumulation of matter which completely absorbs the light from the stars behind it and so hides them from us. The first theory is supported by the facts that the luminous nebula often lies in one end of the "rift," and that the star-density, which in the immediate proximity of the nebula suddenly decreases, in the nebula itself increases again, even if it does not reach its normal value. The fact, however, that the dark canals sometimes reach into the luminous nebula and both here and outside are far branching, and that the "rifts" are often absolutely free from stars except a few bright ones, which are evidently in front of it, is in favor of the second. Anyhow it is rather improbable that the nebula should be of such enormous size that it should destroy the stars altogether to the uttermost limits of the system, because this must be considered to have its greatest extent in the very direction in which these nebulae are observed.

Perhaps both theories separately are correct, so that it is necessary in a single case to decide which influence is the active one. It is, however, obvious that, whatever the conditions may be in the "rifts," the stars which are between the nebula and us must be unaffected by the phenomena. It may be possible to make use of this fact to get an approximate idea of the distance of the nebula, and in the following, this has been tried for the North America nebula.

In 1902 an investigation into the star-density in the vicinity of the North America nebula was published by A. Kopff.[1] The region in question was photographed by means of the 16-inch objective *a* of the Bruce telescope and with an exposure of about 5^h. The plate was divided into small squares, whose sides had the direction N.–S. and E.–W., and the stars contained in each of them were counted. The results obtained in this way are given in a table together with the co-ordinates for the central point of each square, but without any information as to how far the stars indicated on the plate diminish in brightness. The peculiar distribution of the stars, easily observable on the photographs themselves, is verified by this investigation.

In the following table I have set forth some of the figures given in Kopff's work for two zones, which extend across the North America nebula in direction E.–W., lying respectively between $+43°$ to $44°$ and $+44°$ to $45°$ N. Decl. The number of stars in

[1] *Publ. Astroph. Inst. Heidelberg*, 1, 181, 1902.

each zone is stated with respect to small squares, of which one side (N.–S.) is 1°, while the other is the same as in Kopff's original squares. The first column in the table gives the right ascension for the central point of this.

TABLE I

$\delta=$	43°–44°	44°–45°	$\delta=$	43°–44°	44°–45°	$\delta=$	43°–44°	44°–45°
α	n	n	α	n	n	α	n	n
$20^h46^m.2$	90	144	$20^h53^m.3$	148	590	$21^h0^m.4$	141	598
47.0	64	122	54.1	232	532	1.2	184	470
47.8	85	114	54.9	337	626	2.0	299	373
48.6	75	198	55.6	339	604	2.7	526	313
49.4	80	326	56.4	342	634	3.5	625	344
50.2	83	431	57.2	314	603	4.3	718	567
50.9	95	538	58.0	280	738	5.1	728	738
51.7	135	562	58.8	247	721	5.9	775	1036
52.5	131	527	59.6	162	722	....	...	....

For the same two zones I have next by means of the *Bonner Durchmusterung* examined the distribution of stars according to their brightness. Owing to the very small number of stars which could be taken into consideration by this investigation, it was necessary to make the E.–W. side of the squares somewhat larger. In the following table the results are given; the right ascension again refers to the central point of the sides in question.

TABLE II

α	$\delta=43°-44°$					α	$\delta=44°-45°$				
	br. th. $6^m.5$	$6^m.5-7^m.4$	$7^m.5-8^m.4$	$8^m.5-9^m.4$	$9^m.5$		br. th. $6^m.5$	$6^m.5-7^m.4$	$7^m.5-8^m.4$	$8^m.5-9^m.4$	$9^m.5$
20^h42^m	0	1	1	3	2	20^h42^m	0	0	0	12	4
44	0	1	1	5	5	44	0	0	1	6	3
46	0	0	1	5	1	46	0	0	0	11	2
48	1	0	1	7	3	48	1	0	3	4	6
50	0	1	2	1	3	50	0	1	2	8	2
52	0	1	1	3	4	52	0	1	3	9	3
54	1	2	1	0	3	54	0	1	1	7	5
56	0	1	1	0	6	56	0	0	0	7	4
58	0	0	1	3	3	58	0	1	2	5	2
21 0	1	0	1	1	5	21 0	0	0	2	5	6
2	0	0	2	4	4	2	0	0	3	5	3
4	0	1	3	4	2	4	0	1	2	3	2
6	0	0	1	7	8	6	0	0	1	8	7
8	0	1	3	6	3	8	0	0	2	7	4

To show better the distribution of the stars, the foregoing tabulation is given graphically in Fig. 1 and Fig. 2 for the two zones, with the right ascensions as abscissae; the ordinate for Kopff's enumeration has been divided by 10.

The lowest curve, which is derived from a very large number of stars, represents the real law of distribution, and it is evident that the stars, which are at the same distance as the nebula or

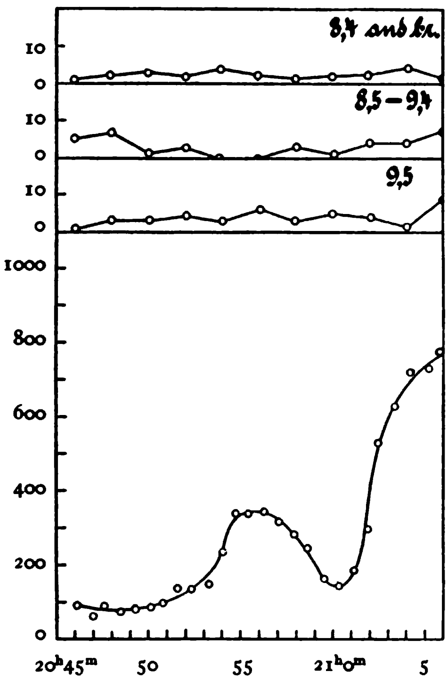


Fig. 1

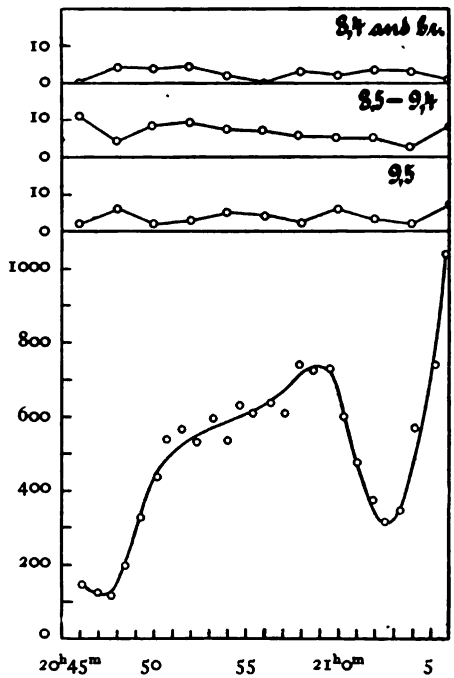


Fig. 2

behind it, must follow this law, whereas stars lying in front must be independent of it. From the drawings it appears clearly that stars of $8^{\text{m}}.5$ and smaller ones follow the law of distribution such as Kopff has found with the well marked minima near $20^{\text{h}}47^{\text{m}}$ and $21^{\text{h}}3^{\text{m}}$, while the brighter stars have absolutely no tendency to decrease in number in these places.

In accordance with the above the parallax of the North America nebula must lie near that of stars of $8^{\text{m}}.5$, which, when no regard

is paid to proper motion, according to Kapteyn, has the probable value of 0."007. As matters now stand, this result fits in well with other parallaxes of nebulae. Kapteyn has from the proper motion derived the mean parallax of the gaseous nebulae and found it to be 0."005, while Newkirk for the central star of the annular nebula of *Lyra* has found 0."07.

As Kopff's investigations extend over a comparatively small area, it has been impossible to follow the curves out to both sides, and find any further correspondence; but in consideration of the small amount of material at our disposal for finding the distribution of bright stars on an area of that size, it is not surprising that the single points of the curves do not lie more continually or that these do not show a more definite shape. Finally for the stars of $9^{m}.5$ it must be remembered that the *B.D.* at this stage of brightness can lay no claim to completeness.

As mentioned above and as may be seen, too, from the drawings, the density of stars will increase in the luminous nebula. This was said in support of the theory that the surrounding dark region is a real hole and not due to the presence of dark nebulous matter; we must suppose that the nebula is most luminous where it has its greatest density as seen from the earth, and where it must consequently absorb the greater part of the light from the stars behind it.

This may be only a hypothesis. The absorption is less dependent on the density than on its constitution, analogous to conditions connected with molecular and colloid dispersions. If, e.g., mastic is dissolved in methylic alcohol, in which it is easily soluble, we get a clear, transparent, molecular-dispersed solution; when, however, a little of this is poured into a large amount of water, the whole will immediately become milky and opaque; it has turned into a colloid solution of mastic in water, which absorbs much more light than the molecular solution, although it contains a much smaller part of matter per unit of volume.

The whole matter is a question of the diameters of the particles, which are suspended in the solution. If they are of such a magnitude that they are able to divert the light, the solution will show the well known Tyndall phenomenon, the particles will scatter the entering light in all directions and let only a little of it pass through.

The same theory may be applied to the nebulae. It is in this connection non-essential what process is the real cause of the luminosity of the nebulae. From the spectra it appears that the nebula in the more luminous parts is molecular, i.e., gaseous, and that it on the contrary does not send out any light from the parts where the nebulous matter eventually is not gaseous. In the few cases where it has been proved that a nebula (especially a spiral nebula) has both a gaseous spectrum and a continuous spectrum, we may assume with a fair amount of certainty that this originates in matter in solid or liquid form and that it is radiation due to temperature. It is very unlikely that such should be the case with the emission of the nebula itself.

In a previous work[1] E. E. Barnard puts the question, What will be the fate of the nebulae "when they die out; for since it does not seem any longer necessary to use these vast bodies of gaseous matter for the making of suns, the dying-out of nebulae is a probability fully as warranted as the belief and certainty that the stars must die out." Perhaps the dark parts may be considered as nebulous matter, which is no longer able to emit light. At any rate it is not unnatural to suppose that the molecules of the gaseous nebula in the outer regions for certain reasons, e.g., temperature, will join together, forming greater particles which do not emit any light themselves but to a certain degree absorb and divert light coming from without. Whether such particles have the structure of dust, solid air, or the like, the nebula in these parts will show a considerably greater absorption, although the absolute density may be far less than in the more luminous part. A nebula of this structure will by intense irradiation show the Tyndall phenomenon, and something of that kind has probably been observed in *Nova Persei*.

Sometimes the star-density is seen to be very variable in the more luminous parts of the nebula too; this may probably originate in the presence of dark matter behind. Surely interesting information about the physical constitution of the gaseous nebulae may be had by observing the light-curves in light of both short and long wave-lengths for variable stars, which are behind a nebula, and whose light must pass through it, and then comparing the results

[1] *Astrophysical Journal*, 25, 218, 1907.

with such as are obtained from regions as free from nebula as possible. The effect on light passing through an air-mass of the same size as the North America nebula (computed from the parallax mentioned above) will be a shift between red and violet rays of several minutes, even if the average density of the air is only a fraction of an atmosphere.

As mentioned before, this particular dependence of the star-density on a nebula appears by no means in all nebulae. Objects like the *Andromeda* nebula, etc., with a continuous spectrum show no effect on the stars in the vicinity. The phenomenon seems to appear only in gaseous nebulae and mostly together with the great irregular nebulae which lie in or near the Milky Way. Whether any attention is to be paid to this latter fact cannot yet be decided; the phenomenon may be present even if its extension or the star-density in the vicinity is so inconsiderable that we are not able to observe it.

It may with certainty be said that nebulae which are observed in connection with such characteristic dark regions (whatever their real nature may be) belong to our stellar system, and by using the method described in this paper for other objects as well, perhaps some results can be gained which will have value by being more than merely hypothetical.

Urania Observatory
Copenhagen
March 1913

THE SPECTRA OF MERCURY IN THE SCHUMANN REGION

By THEODORE LYMAN

The spectra of mercury in the Schumann region are of some interest at the present time, partly because of their bearing on the subject of series relations and partly because the mercury arc in quartz has been recently extensively employed in photo-chemical, biochemical, and photo-electric researches.

Very little is known of the spectra in the region on the more refrangible side of λ 1900. The work of Huff[1] has carried the Geissler-tube spectrum to λ 1872.2. A single line in this spectrum near λ 1850 has long been familiar to me and was observed by Handke[2] in 1909. The spectrum of the mercury arc in quartz has been investigated by several observers. Hughes[3] found a strong line near λ 1850 and Tian,[4] working with a vacuum prism spectroscope, corroborated the observation, while, with a spectroscope in air, he found lines at λ 1846 and λ 1848.[5] Henri,[6] Fabry and Buisson,[7] and others have investigated the connection between the radiation and the electric conditions of the arc.

As my vacuum grating spectroscope is better adapted to the investigation of the Schumann region than the instruments used by the investigators just mentioned, it seemed worth while to take up the subject.

The arrangement for studying the spark spectrum was exactly similar to that employed in my work on the spectra of the alkali earths.[8] A strontium amalgam, a barium amalgam, and a globule of mercury were used successively as terminals. The spark was in an atmosphere of hydrogen. The spectra obtained with the three substances are practically identical. They are characterized by

[1] Kayser, *Handbuch*, **5**, p. 548.

[2] Inaug. Diss., Berlin, 1909.

[3] *Proc. Camb. Phil. Soc.*, **16**, 428, 1912.

[4] *Comptes rendus*, **155**, 141, 1912.

[5] *Ibid.*, **152**, 1483, 1911.

[6] *Ibid.*, **153**, 426, 1911.

[7] *Ibid.*, **153**, 93, 1911.

[8] *Astrophysical Journal*, **35**, 344, 1912.

numerous lines extending from λ 1876 to the limit set by the transparency of fluorite. All the strong lines lie between λ 1876 and 1650. The lines do not present any very obvious regularity of arrangement.

Two forms of mercury arc were employed. In one, the whole vessel was of quartz, and the light entered the spectroscope through the side of the lamp. In the other, the vessel was of glass fitted with a fluorite window. The spectrum is dominated by the broad unsymmetrical line at λ 1849.6, which considerably exceeds in strength any single line in this region in the spectrum of any substance with which I am acquainted. The line is easily reversed, a fact which has already been noted by Tian.[1] The other six lines which go to make up the arc spectrum, though much inferior in intensity, are still fairly strong.

The relation between the spark and arc spectra is what one would expect from the behavior of mercury in the visible and ultraviolet, for the spark spectrum is rich in lines and the arc spectrum contains but few.

From the point of view of theory, it is interesting to note that the lines at λ 1849.6 and λ 1402.5 in the arc are the two first members of the main series predicted by Paschen;[2] the third member, which should occur at λ 1268.9, is within the limit of the transparency of fluorite, but I have not been able to find it. This was to be expected, for, as the intensity falls off very rapidly between λ 1849.6 and λ 1402.5, the next line in the series must be very faint indeed. The members of the second series,[3] λ 1435.6, 1307.8, 1259.3, and 1235.9, cannot be found in the arc, though 1307.8 occurs faintly in the spark. This does not necessarily show that the prediction is wrong, for experimental difficulties render the detection of faint lines beyond λ 1350 almost impossible.

Hughes[4] predicted the nature of the spectrum of the mercury arc in the Schumann region, basing his conclusions on photoelectric data. Later experiments[5] have somewhat changed his numerical values. Neither the original prediction nor the corrected data agree with the spectrum as I have found it.

[1] *Comptes rendus*, **155**, 141, 1912.

[2] *Ann. d. phys.*, **35**, 860, 1911.

[3] *Ibid.*, **40**, 605, 1913.

[4] *Phil. Mag.*, **21**, 393, 1911.

[5] *Phil. Trans. Roy. Soc. Lond.*, **212**, 205, 1912.

Following my usual practice, the observations which have been recorded were obtained after the spectroscope had been repeatedly exhausted and washed with dry hydrogen. If a photograph was taken with air in the spectroscope, the appearance of the line at λ 1849.6 was profoundly modified. The broad line, which often extended over thirty angstroms, was now replaced by three groups of rather faint, sharp lines. This is, undoubtedly, the phenomenon observed by Steubing,[1] and this is the phenomenon which all investigators will observe who work with an apparatus in which the light from the mercury arc must traverse a considerable air-path before falling on the photographic plate. It is possible that some of Tian's measurements refer to the strongest of these lines or bands. Except for these lines, there is nothing visible in the mercury arc below λ 1900 when investigated through air.

Steubing has attributed the lines to the fluorescence of oxygen, and their narrowness and sharpness lend color to this interpretation. It is not impossible, however, that the effect is produced by the absorption of the air after the light has passed through the slit in the spectroscope. Absorption must enter into the phenomenon, even if Steubing's view is correct.

When the mercury arc in quartz is employed in photo-chemical, biochemical, and photo-electric experiments, it is obvious that very different results may be expected, if the light has to traverse a short air-path, from those which will result if the air-path is long. In the first case, the full energy of the great line at λ 1849.6 will be effective; in the second, only the feeble action of Steubing's lines will be felt. It is well for workers in these fields to bear this fact in mind. Experiments show that biochemical, like photo-electric action, increases rapidly with decrease in wave-length. It is, therefore, this line λ 1849.6 which, of all lines in the mercury spectrum, is the most active in producing *abiotic* effects when the organisms under observation can be brought into close proximity to the lamp. In this connection, one must remember that even fused quartz is sufficiently transparent to transmit this radiation strongly. On the other hand, it must not be forgotten that water in thickness of even one millimeter is very opaque at λ 1850.[2] The scarcity and

[1] *Ann. de phys.*, **33**, 572, 1910. [2] *Nature*, **84**, 71, 1910.

feeble nature of the other lines in the Schumann region render the mercury arc inefficient in producing effects which depend on shorter wave-lengths. For example, the light from the mercury arc produces far less volume ionization than results from the use of a hydrogen tube.

A detailed account of the experiments follows. The spark chamber and the manner in which it was attached to the spectroscope is shown on p. 344 of the *Astrophysical Journal*, **35**, No. 5. All the apparatus and the experimental procedure were exactly as there described. The exposures were usually 20 minutes.

The strontium amalgam contained about 75 per cent of mercury. The barium amalgam contained about 80 per cent of mercury. When pure mercury itself was employed, it was held in a steel cup; the upper electrode was a point of soft steel. As has already been observed, the three spectra obtained in this way are nearly identical. The spectrum obtained with pure mercury, however, was quite feeble in the more refrangible end of the spectrum; in fact, beyond λ 1750 all the lines are very faint and the group beyond λ 1350 cannot be seen at all. This is probably due to the absorption of the metallic vapor round the spark. That the lines between λ 1750 and λ 1260 are due to mercury itself, is proved by the behavior of the amalgams. For, though the strontium amalgam was of rather doubtful character, the barium amalgam was known to be pure. The spectra of these two substances are identical; it seems probable, therefore, that their common spectrum is due to their common ingredient, namely, mercury.

Table I contains the wave-lengths in vacuum with the frequencies added for the convenience of those who may be interested in computations connected with series spectra. The line λ 1849.6, so strong in the arc, appears in the amalgam spectrum as a faint band; it is reversed in the spark from mercury itself. Of the remaining six arc lines, only two surely appear in the spark. The values in the table have been compared with those for aluminum, iron, and the alkali earths, and I hope most of the impurities have been eliminated. The measurements were made by the method of shifted spectra.[1] The absolute position of the lines should not be

[1] *Astrophysical Journal*, **23**, 202, 1906.

TABLE I

Spark		Arc		
λ	I	λ	I	1/λ
1269.7	5	......	......	78758
1277.1	4	......	......	78302
1280.7	4	......	......	78082
1305.6	3 ?	......	......	76593
1307.9	2	......	......	76458
1321.4	3	......	......	75677
1323.2	4	......	......	75574
1326.4	4	......	......	75392
1330.8	7 *Ba?*	......	......	75143
1335.4	5	......	......	74884
1350.4	3	......	......	74052
1361.0	4 *Ba?*	......	......	73475
1378.0	1	......	......	72569
1379.0	1	......	......	72516
1400.4	2	......	......	71408
		1402.5	6	71301
1404.3	1	......	......	71209
1414.4	4	......	......	70701
1416.9	4 *Ba?*	......	......	70576
1481.6	1	......	......	67494
1495.0	3	......	......	66889
		1518.6	3	65850
1527.4	5	......	......	65470
1540.5	2	......	......	64914
1548.4	1 ?	......	......	64583
1550.8	2 ?	......	......	64483
1561.0	1 ?	......	......	64061
1568.0	2	......	......	63775
1570.3	1	......	......	63682
1592.9	8 ?	......	......	62778
1599.4	7	......	......	62523
1641.5	1	......	......	60919
1647.4	9	......	......	60702
1649.8	10 *br*	1649.8	8	60613
1652.5	3	......	......	60514
1654.7	5	......	......	60434
1656.9	3 ?	......	......	60353
1662.6	7	......	......	60146
1670.1	1	......	......	59876
1671.0	7	......	......	59844
1672.5	4	......	......	59790
1677.9	10	......	......	59598
1681.6	1	......	......	59467
1692.7	2	......	......	59077
1695.0	2	......	......	58997
1716.6	1	......	......	58254
1718.1	2	......	......	58204
1720.7	2	......	......	58116
1724.2	1	......	......	57997
1726.8	1	......	......	57911
1735.8	1	......	......	57610
1738.3	8	......	......	57527
1740.2	6	......	......	57464
1741.0	2	......	......	57438

TABLE I—*Continued*

Spark		Arc		
λ	I	λ	I	1/λ
1742.7	2	......	......	57382
1745.2	1	......	......	57300
1751.5	1	......	......	57094
1756.0	2	......	......	56947
1759.7	6	......	......	56828
1764.0	1	......	......	56689
1770.1	1	......	......	56494
		1774.9	5	56341
1775.2	3	......	......	56331
1780.0	1	......	......	56179
1787.7	1	......	......	55938
1792.7	5	......	......	55781
1796.2	7	......	......	55673
1798.7	9	......	......	55595
1800.7	1	......	......	55534
1803.9	3	......	......	55435
1806.5	2	......	......	55355
1808.3	2	......	......	55300
		1810	3 band	55248
1816.1	1	......	......	55063
1820.8	10	......	......	54921
1823.8	3	......	......	54830
1826.2	4	......	......	54758
1832.7	6	1832.6	4	54564
1837.1	1	......	......	54433
1840.8	7	......	......	54324
1849.0	5	......	......	54083
1849.6	5 reversed	1849.6	>100	54065
1850.3	3	......	......	54045
1853.4	4	......	......	53954
1859.5	2 *br*	......	......	53778
1861.0	1	......	......	53734
1862.3	1	......	......	53697
1865.1	1	......	......	53616
1869.4	10 *br*	......	......	53493
1875.7	6	......	......	53313

in error by more than three-tenths of an angstrom unit. The relative distance between neighboring lines, which involves the setting error only, should be accurate to about one-tenth of a unit.

My work on the mercury spectrum from a vacuum tube in the region below λ 1900 has been carried on only at pressures under 3 or 4 mm and has been mostly incidental to the study of gas spectra. I am able to recognize but one line, that at λ 1849.6. Handke[1] gives the line λ 1850.0. The difference of four-tenths of a unit between his value and mine is not confined to this particular line.

[1] *Op. cit.*

All his measurements in this region give results about half a unit higher than mine.

In my work on the arc in quartz, two lamps were employed; they were both of the form shown in Fig. 1. They were constructed of tubing 1 cm in external diameter; the portion between the electrodes was 13 cm long. The drawing is very nearly to scale.

In one of the lamps, on the side of the tube at *A*, a small bulb was blown. This bulb was then flattened, as well as might be, and formed a rough window. When the exposure was to be made, the

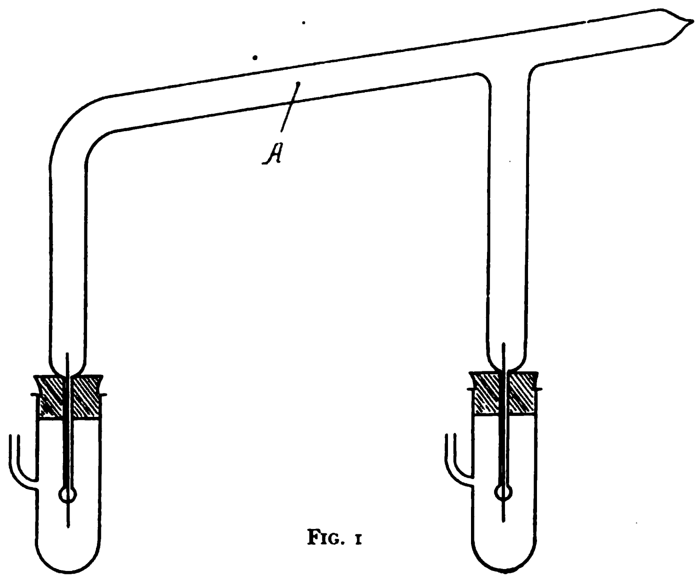


Fig. 1

flattened portion of the lamp was pressed against the fluorite window of the spectroscope, the free air-path being of the order of two-tenths of a millimeter. The other lamp had no bulb; the tube was pressed directly against the spectroscope window. Both lamps yielded the same results. The lamps were exhausted in the usual manner and then sealed; they were started by tipping. A current of 1.5 amperes was employed; the drop across the terminals was 80 volts. The exposure was usually about five minutes and was always terminated either by the cracking of the fluorite window or by the melting of the cement which held it in place on the spectroscope.

The line λ 1774.9 is the most refrangible radiation on these plates. The fact that the spectrum terminates at this point is probably due to two causes: first, the absorption of the quartz, and second, the absorption of the dense mercury vapor itself. The broad line or band at λ 1849.6 is always unsymmetrical, the maximum of intensity lying well toward the more refrangible side. With the quartz lamp, the band is always strongly reversed; the width of the whole band is usually about 30 or 40 units; the reversed portion is about 6 units wide.

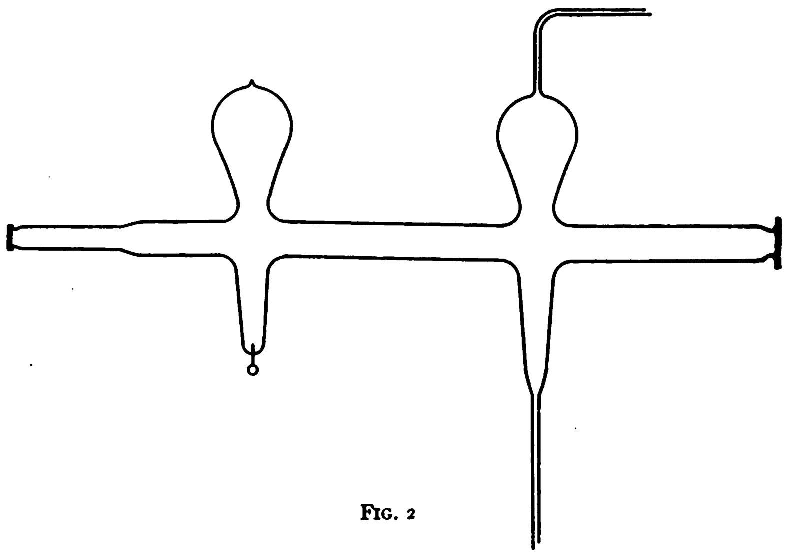


FIG. 2

The second type of lamp was designed to do away with the absorption of quartz and to enable experiments to be made with the mercury vapor at low pressures. With it, the line λ 1849.6 could be obtained unreversed, and with it, the lines below λ 1775 were discovered. It is illustrated in Fig. 2. The end next the spectroscope was closed by a fluorite plate attached with Khotinski cement and was 24 cm from the nearest mercury electrode. In the final arrangement, the end was fitted into a brass cone (not shown in the sketch) which, in turn, made an air-tight joint with a cup attached to the face plate of the spectroscope, the arrangement being exactly that illustrated on p. 102 of Vol. **33** of this *Journal*. Thus the light from the mercury lamp passed through only one fluorite window

about 1 mm thick before entering the spectroscope. The arc was started by raising the mercury in the barometer column which formed one of the electrodes. During an exposure, the lamp was always connected to a powerful Trimount mechanical pump; the pressure, registered on a McLeod gauge situated midway between lamp and pump, was always less than one one-hundredth of a millimeter.

Though the arrangement was simple yet the experiments proved difficult and tedious. This was mainly due to the formation of opaque films on the fluorite window, which always necessitated breaking the air-tight joint between the lamp and the spectroscope and sometimes even required the removal of the window from the lamp itself. Because of the danger to the spectroscope from mercury vapor, the window could never be discarded altogether.

The lamp took 4 amperes with 25 volts drop in potential across the terminals. The time of exposure necessary to bring out the fainter lines in the spectrum was about fifteen minutes. A record of the line at λ 1849.6 could be obtained with ten seconds' exposure, however.

Even with this form of lamp, the line at λ 1849.6 is sometimes reversed. It is also very sensitive to the presence of films on the window. This may partly explain the decay of the efficiency of the mercury arc with time, which has been recorded by several observers.[1] In the quartz arc, however, where the whole system remains very hot, the formation of films is probably not the important factor. The observed effect may well be due in part to a change in the quartz itself under the action of the ultra-violet light similar to that which I have observed with fluorite. With this substance, long exposure in the Schumann region will turn transparent, colorless fluorite into an opaque modification of a purple tinge. Dr. Nutting has observed the same change of color with glass.

It is interesting to note that Steubing's lines were obtained both with the quartz lamp and with the arc at low pressures.

The third column in the table gives the wave-lengths of the arc lines in vacuum. The line at λ 1849.6 was measured by direct

[1] *Comptes rendus*, **155**, 141, 1912.

comparison with the spark lines of aluminum. The other wave-lengths were found by comparison with a shifted spectrum of iron. Owing to the broad character of the arc lines and to the strong background due to scattered light, the setting error is larger than in the case of spark lines and the results may not be so accurate. Estimating the intensities which are given in the fourth column is a difficult matter. The line at λ 1849.6 is vastly stronger than any of the others and I have indicated the fact by the expression >100. The line marked "8" appears to have the same intensity as a line marked "8" in the hydrogen spectrum lying in the same region. It is obvious that these numbers give but a rough measure of the relative intensities.

The small number of lines in the arc spectrum is striking and may be partly attributed to the absorption of the mercury vapor within the lamp itself. Hughes predicted this scarcity of radiation from his photo-electric observations, but his estimate of the position of these lines turns out to be quite inaccurate even when his computation is corrected to agree with his recent experiments.

It is to be regretted that experimental difficulties made it impossible to verify Paschen's predictions beyond λ 1300. Radiation of wave-lengths shorter than λ 1300 must be strongly absorbed by fluorite, if not by the vapor in the lamp itself, and, therefore, only lines of the strongest character can be detected in this region.

I hope the results of this investigation may be of some value, first, because two of the important lines predicted by Paschen have been discovered; second, because of the information which has been obtained on the subject of the spark spectrum; third, because the nature of the arc spectrum has been determined and thus the radiation from the quartz mercury lamp has been definitely settled.

Jefferson Laboratory
Cambridge

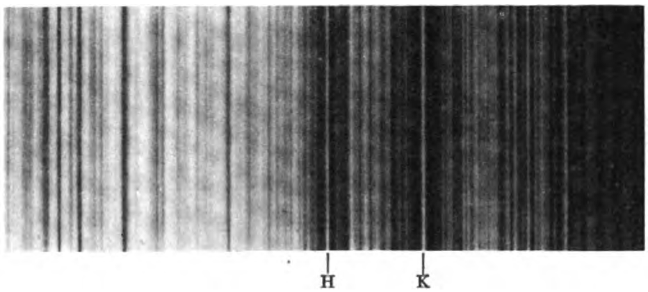
Minor Contributions and Notes

ON THE REVERSAL OF THE CALCIUM LINES H AND K IN STELLAR SPECTRA

During the year 1900 G. Eberhard and H. Ludendorff at the request of H. C. Vogel made photographs of stellar spectra with the small spectrograph D, which were intended particularly for the study of the ultra-violet. In the visible part of the spectrum these plates were very strongly overexposed. Eberhard found on such a plate of *Arcturus* that the K line of calcium shows a sharp reversal, that is, a calcium emission takes place in the middle of the absorption line just as one observes it in a disturbed region of the solar surface. As the absorption in the broad calcium line is very strong and the emission rather weak, the reversal is visible only on a plate in which the continuous spectrum in the neighborhood of the H and K lines is strongly overexposed. Further observations of this same phenomenon have recently been made by Schwarzschild with an objective-prism. On the plates of the *Hyades*, referred to in the preceding paper, taken with the U.V. Zeiss triplet and U.V. objective-prism (150 mm aperture, 1500 mm focus, dispersion 10 mm between H_γ and K) are found strongly exposed spectra of *Aldebaran*, which likewise show reversal of the K line and, although more weakly, a reversal of H. Similar exposures on *a Aurigae* and *a Ursae Majoris* failed to show reversal; neither did exposures on *a Orionis* and *a Cassiopeiae* show it. In the case of the last two it is perhaps true that the exposure was not sufficiently strong. An exposure of one hour on *β Geminorum* with the objective-prism showed no reversal, but on the same plate a neighboring star, *σ Geminorum*, shows extraordinarily bright, sharp emission lines in the middle of the absorption lines.

Although a mere examination of the spectra makes it very probable that one is dealing with a real emission phenomenon and not merely with a vacant space in the continuous spectrum, it

seems advisable to investigate the relation of this line to calcium by a determination of its wave-length. In the following the results of such measures are given as differences in radial velocity. The reversals were compared with 7 to 10 of the neighboring star lines due to *Fe* and *Al*.



Spectrum of *σ Geminorum* taken with the Zeiss triplet and U.V. objective-prism, 1913, March 9. Enlarged and broadened about 12 times.

α Boötis

Great Refractor. Spectrograph III with short camera. Slit-width 0.10 mm, width of spectrum 0.05 mm. February 23, 1913. Exposure 30^m

H -3 km/sec., K $+6$ km/sec.

α Boötis

Zeiss triplet with objective-prism. Width of spectrum 0.2 mm. April 23, 1912. Two exposures of 14^m and 7^m. The mean of both taken.

H $+5$ km/sec., K $+5$ km/sec.

α Tauri

The same apparatus. January 14, 1912. One exposure of 30^m. January 1, 1913. Two exposures of about 30^m each. Mean of all three.

H -3 km/sec., K $+3$ km/sec.

σ Geminorum

The same apparatus. March 9, 1913 and March 12, 1913. Each exposure about 60^m. Mean of the two.

H -6 km/sec., K -7 km/sec.

Since in the vicinity of H and K 1 μ equals 1.2 km/sec. with the spectrograph and 2.6 km/sec. with the objective-prism, the above numbers probably only mean that the wave-lengths of the reversals agree within errors of measurement with the wave-lengths of the H and K lines. The brightness of the H and K reversals in the case of σ *Geminorum* is so great that their blackening of the plate equals that of the brightest part of the continuous spectrum between H and K. The width of the emission line amounts to about one Å.U. on the plate taken March 12. On account of the unsteadiness of the air and the pointing error this is not a measure of the width of the line, which presumably is small, but only indicates the strength of the radiation. In the case of *Aldebaran* it is shown, by a comparison of its spectrum with that of other stars in the *Hyades* photographed on the same plate, that the brightness of the reversal with an equal width is relative to the continuous spectrum about three magnitudes weaker than that of σ *Geminorum*. *Arcturus* shows a slightly stronger reversal than *Aldebaran*. K is stronger than H in all the three stars. In a high-dispersion spectrum of the sun a very fine, weak reversal of the K line is seen all over its surface. In a detached region of disturbance the reversal reaches a strength as great as in σ *Geminorum*. In order to get an idea of the average strength of emission of the sun compared with that of the star, the spectrum of diffuse skylight was photographed with the same dispersion on March 14, 1913. The spectrum of diffused skylight of course corresponds to the average spectrum of the sun. This plate showed no sign of reversal of the H and K lines. From this we conclude that the emission is much stronger in these stars than in the sun.

The following general remarks may be added. Reversals of lines in stellar spectra are not rare. The reversals found here are interesting in that they take place in stars whose spectra are similar to that of the sun and therefore more comprehensible to us. The same kind of eruptive activity that appears in sun-spots, flocculi, and prominences, we probably also have to deal with in *Arcturus* and *Aldebaran* and in a very greatly magnified scale in σ *Geminorum*. This agrees with Adams'[1] result for *Arcturus*, viz.,

[1] *Astrophysical Journal*, **24**, 69, 1906.

its absorption lines show the transition from the normal solar spectrum to the spot spectrum.

Two problems arise in this connection. It remains to be shown whether the emission lines of the star have a possible variation in intensity analogous to the sun-spot period. It is known as a result of the investigations of Deslandres[1] and of St. John[2] that the centers of the calcium emission of the sun have a radial outward motion of 1 km per second. A more accurate determination of the wave-lengths of the calcium emission of the stars should prove whether or not a greater total intensity of emission is accompanied by a greater velocity of ascent.

G. EBERHARD
K. SCHWARZSCHILD

ON THE RADIAL VELOCITY OF *63 TAURI*

For the determination of radial velocities by means of the objective-prism E. C. Pickering has proposed the method of making two exposures of a star field on the same plate, reversing the prism 180° between the exposures. The distances of corresponding lines in the two spectra of each star then depend upon its radial velocity, and the measurement of these distances makes it possible to obtain the radial velocity after the lines have been identified, and the necessary reduction constants have been applied.

Instead of determining the radial velocity itself, the problem may be limited to finding variation in radial velocity by means of a comparison of two plates with such double exposures. Let the linear distance for a star on the first plate equal s, on a second equal s', then the difference $s'-s$ at once measures the change in radial velocity of the star if the observing conditions were absolutely identical. The inevitable changes in these conditions have the result that to the effect of the radial velocity is added that of a linear function of the rectangular co-ordinates x, y of the star. For the measured distances $s'-s$ we have equations of the form $s'-s=\alpha+\beta x+\gamma y+\Delta(s'-s)$, in which α, β, γ are plate-constants depending upon the observing conditions and in which the only remaining

[1] *Comptes rendus*, 1905, 381.

[2] *Astrophysical Journal*, 32, 36, 1910.

term, $\Delta(s'-s)$, represents the effect of the variable radial velocity. The three constants α, β, γ may be determined from stars whose radial velocities are constant. By deriving the remainder $\Delta(s'-s)$ for the other stars, the change in radial velocity may be obtained from it without further trouble. In case not only linear but also quadratic terms should have appreciable values in the expression for $(s'-s)$, these may easily be got by direct computation, as will be shown elsewhere.

The measurement of the difference $s'-s$ is made in the simplest manner by optically juxtaposing the spectra from the two plates by reflection. This I accomplished by means of the Zeiss stereo-comparator after making a small alteration in its "Blink" microscope. The advantages are the same as in the method of measuring spectrograms with the Hartmann spectrocomparator.

Groups of lines of both spectra may be brought to view, identification of the lines is superfluous, and since the comparison is between two spectra of one and the same star it is possible to employ also the extremely weak lines, which on a single plate one would hardly dare to use.

Whether this method will come to be of any importance, in the search for variable radial velocities, compared with the performance of the great telescope and slit-spectrograph is a question about which I hardly dare to express an opinion. Meanwhile I can communicate a result which I have obtained by means of it. Three double exposures on the *Hyades* made on January 10, 1912, January 1 and January 4, 1913 were compared in the manner described above. The instrument with which they were taken was the Zeiss triplet of 150 mm aperture and 1500 mm focal length, combined with an objective-prism having a dispersion of 10 mm from H_γ to K. The comparison yielded for the star *63 Tauri* (1900.0, $4^h17.7^m$, $+16°33'$) the following deviation from the mean value (unknown): + 5 km/sec., −37 km/sec., + 33 km/sec.

As the star has good lines these numbers exceed by a great deal the errors of observation, and it is safe to conclude that this star has a variable radial velocity of short period and of large amplitude. The magnitude of this star is given in *H.R.* as 5.68, its type as A2. In *P.D.* its magnitude is 5.93. Its spectrum may be obtained in

60^m with the large refractor and spectograph III, since the spectrograph has been equipped with a short camera having the new chromat[1] lens of 180 mm focal length and ratio 1:4.5. Plates taken with the spectrograph confirmed the variation. The amplitude of variation may be 70–80 km/sec., the period in the neighborhood of eight days. A more exact investigation is in progress.

Because of its proper motion and evidently also because of its mean radial velocity, this star belongs physically to the *Hyades*. According to Hertzsprung[2] it is abnormal in that it has a K line which is weaker compared with the hydrogen lines than the K line of other stars of equal magnitude belonging to the *Hyades* system.

K. Schwarzschild

THE CONDITION FOR ACHROMATISM AND ANASTIGMATISM IN A SYMMETRICAL PHOTOGRAPHIC DOUBLET CONSISTING OF FOUR SEPARATED THIN LENSES

In applying the elegant methods for discussing the aberrations of systems of lenses, published by Taylor in his *A System of Applied Optics* to that type of photographic objective, such as the Goerz "Celor" and "Syntor," and the Steinheil "Unofocal," which consists of four separated thin[3] lenses arranged in the form of a symmetrical doublet, I discovered a simple relation which must be satisfied in order that the objective may be as free as possible from the errors of achromatism and astigmatism. As I have never run across this law in print, it has occurred to me that it may be new to others and that it is of sufficient interest to warrant its publication. This condition stated in general terms is as follows: *The separation between the positive and negative lens minus the focal length of the negative lens must equal the focal length of the positive lens multiplied by the square root of the ratio of the indices of refraction divided by the ratio of the dispersive powers.*

[1] *Sitzungsber. d. Berl. Akad. d. Wiss.*, p. 1220, 1912.

[2] *Publ. des Astrophys. Observatoriums zu Potsdam*, No. 63, p. 35.

[3] As actually constructed, these lenses are not *mathematically* thin and hence the following law does not apply with full rigor.

The proof of this proposition is as follows: on p. 285 Taylor gives for the achromatism of n separated thin lenses the following expression:

$$\Delta\frac{1}{v_n}=\frac{1}{f_1}\frac{\Delta\mu_1}{\mu_1-1}\left(\frac{v_1v_2\ .\ .\ .\ v_{n-1}}{u_2u_3\ .\ .\ .\ u_n}\right)^2+\frac{1}{f_2}\frac{\Delta\mu_2}{\mu_2-1}\left(\frac{v_2\ .\ .\ .\ v_{n-1}}{u_3\ .\ .\ .\ u_n}\right)^2\ .\ .\ .+\frac{1}{f_n}\frac{\Delta\mu_n}{\mu_n-1}. \tag{1}$$

In the above expression the v's denote the distances of the image formed by any lens from the lens and the u's the distances of the objects, the f's being the focal lengths. In the special case under consideration let the focal lengths be f, $-kf$, $-kf$, and f and the separations be t, $2d$, and t, d being, therefore, the distance of the stop from the second lens of the system. We shall also have $\mu_1=\mu_4$ and $\mu_2=\mu_3$. Let us put $a=\frac{\mu_1-1}{\Delta\mu_1}\cdot\frac{\Delta\mu_2}{\mu_2-1}$. Introducing these values into (1) we have at once:

$$\Delta\frac{1}{v_4}=\frac{1}{f}\frac{\Delta\mu_1}{\mu_1-1}\left\{\left(\frac{v_1v_2v_3}{u_2u_3u_4}\right)^2-\frac{a}{k}\left[\left(\frac{v_2v_3}{u_3u_4}\right)^2+\left(\frac{v_3}{u_4}\right)^2\right]+1\right\}=\frac{1}{f}\cdot\frac{\Delta\mu_1}{\mu_1-1}G. \tag{2}$$

In order to evaluate G we proceed as follows: from the ordinary law of conjugate focii we have

$$\frac{1}{u_2}=\frac{1}{v_2}+\frac{1}{kf}$$

or

$$u_2=\frac{kfv_2}{kf+v_2}.$$

But evidently we have

$$u_2=v_1-t$$

whence we obtain

$$v_1=\frac{kfv_2+kft+v_2t}{kf+v_2}$$

and, therefore,

$$\frac{v_1}{u_2}=\frac{v_2(kf+t)+kft}{kfv_2}.$$

In the same way it may be shown that

$$\frac{v_3}{u_4}=\frac{kfu_3}{(kf+t)u_3-kft}.$$

From these it readily follows, after a slight reduction, that

$$\frac{v_1v_2v_3}{u_2u_3u_4}=\frac{v_2(kf+t)+kft}{u_3(kf+t)-kft}$$

$$\frac{v_2v_3}{u_3u_4}=\frac{kfv_2}{u_3(kf+t)-kft}.$$

Substitute these values into the expression for G and we have:

$$[v_2(kf+t)+kft]^2-\frac{a}{k}[k^2f^2v_2^2+k^2f^2u_3^2]+[u_3(kf+t)-kft]^2=AG$$

where

$$A=[u_3(kf+t)-kft]^2\,. \tag{3}$$

Let $y=v_2-d$. We then have $v_2=y+d$ and, since $u_3=v_2-2d$, $u_3=y-d$. Introducing these values we have, after reduction:

$$[v_2(kf+t)+kft]^2=(kf+t)^2(y^2+2dy+d^2)+2kft(kf+t)(y+d)+k^2f^2t^2$$

$$[u_3(kf+t)-kft]^2=(kf+t^2)(y^2-2dy+d^2)-2kft(kf+t)(y-d)+k^2f^2t^2$$

$$[v_2(kf+t)+kft]^2+[u_3(kf+t)-kft]^2=$$

$$2(kf+t)^2(y^2+d^2)+4akft(kf+t)d+2k^2f^2t^2\,.$$

In the same way we have:

$$k^2f^2v_2^2+k^2f^2u_3^2=2k^2f^2[y^2+d^2]\,.$$

Introducing these values into equation (3) we find, after a slight reduction,

$$y^2[(kf+t)^2-akf^2]+[d(kf+t)+kft]^2-akd^2f^2=\tfrac{1}{2}AG\,.$$

This gives finally

$$\Delta\frac{1}{v_4}=\frac{2}{f}\cdot\frac{\Delta\mu_1}{\mu_1-1}\left\{\frac{y^2[(kf+t)^2-akf^2]+[d(kf+t)+kft]^2-akd^2f^2}{[(y-d)(kf+t)-kft]^2}\right\}.$$

Let us divide both terms of this fraction by f^4:

$$\Delta\frac{1}{v_4}=\frac{2}{f}\cdot\frac{\Delta\mu_1}{\mu_1-1}\left\{\frac{\frac{y^2}{f^2}\left[\left(k+\frac{t}{f}\right)^2-ak\right]+\left[\frac{d}{f}\left(k+\frac{t}{f}\right)+k\frac{t}{f}\right]^2-ak\left(\frac{d}{f}\right)^2}{\left[\left(\frac{y-d}{f}\right)\left(k+\frac{t}{f}\right)-k\frac{t}{f}\right]^2}\right\}.$$

Now in this type of objective the separations are kept as small as possible and hence $\frac{t}{f}$ and $\frac{d}{f}$ are small in comparison to $\frac{y}{f}$ since y is the distance that the focus of the first combination is back of the stop. The second and third terms in the numerator are then considerably smaller than the first. Furthermore, it is to be noted that the first term of the numerator is the only one that varies with the distance of the object from the lens; hence it follows that, everything considered, the best achromatism will be reached in this type of lens if the first term be made zero, which gives us

$$(kf+t)^2-akf^2=0$$

or

$$kf+t=f\sqrt{ak}\,. \tag{4}$$

Now in order that the excentric corrections due to the stop may be exactly three times in the primary plane what they are in the secondary plane and hence be simultaneously made equal to zero, the well known Petzval condition must be satisfied, namely,

$$\Sigma\frac{1}{\mu f}=0=2\left[\frac{1}{\mu f}-\frac{1}{k\mu_2 f}\right]$$

whence

$$k\mu_2-\mu_1=0$$

or

$$k=\frac{\mu_1}{\mu_2}\,.$$

Hence in (4) k is the ratio of the indices of refraction and, as was shown above, a is the reciprocal of the dispersive powers.

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THE INTERNATIONAL UNION FOR CO-OPERATION IN SOLAR RESEARCH

The fifth conference of the Union was held in Bonn. Germany, from July 30 to August 5, 1913. On the first day of the conference the sun appeared for the first time in several weeks, and it continued to shine until the Union adjourned to meet in Rome in 1916.

The welcome extended by the local hosts to the visiting scientists was no less warm than that bestowed upon them by the object of their research, and the delightful social features arranged for their entertainment will always be remembered with the greatest of pleasure.

On the evening of July 30 the city of Bonn gave a banquet in their honor. During the afternoon and evening of August 1, Professor and Mrs. Küstner gave a reception and tea at the Bonn Observatory. On the next day the city of Cologne entertained the Union, the program including a tour of the city, visits to the cathedral and art gallery, and a banquet in the Gürzenich. Sunday, August 2, was devoted to excursions. A part of the company took an all-day tramp through the Siebengebirge; the rest, to the number of about 60, went on an automobile tour through the Eifelgebirge to Cochem, down the valley of the Mosel to Coblenz, and back along the Rhine to Bonn, a total distance of 130 miles. The sixteen machines used were kindly loaned by residents of Bonn.

Monday evening, August 4, was devoted to a *conversazione* in the Physical Institute. An opportunity was given for an informal exchange of ideas upon a great variety of subjects, not necessarily associated with solar research. In the various rooms there were exhibits by Chrètien, Donitch, Goos, Hemsalech, Hertzsprung, Leybold, W. Michelson, Pflüger, E. C. Pickering, Russell, Slocum, Störmer, Stratton, de Watteville, and Wolf. This proved to be a most enjoyable and profitable occasion and may become a permanent feature of the Union conferences.

Tuesday afternoon and evening Professor Kayser gave a party on the Rhine. This included an excursion up the river to Rolandseck, visit to the oldest ruin on the Rhine, and dinner

on board the boat. Upon the return of the steamer to Bonn, many of the party took a night train to Hamburg to be present at the first meeting of the Astronomische Gesellschaft the next morning.

There were five formal scientific sessions of the conference, presided over respectively by Professors Kayser, Küstner, Schwarzschild, Runge, and Pringsheim. Professors Konen, Fowler, Hemsalech, and Count de la Baume Pluvinel acted as secretaries.

The sessions were devoted chiefly to the consideration of the reports of the various committees, appointed to promote co-operation in solar research and allied investigations. Nine committees reported.

In the absence of Professor Schuster, Professor Turner acted as chairman of the Executive Committee and presented its report. Professor Turner also presented the report of the Computing Bureau. The work of the Bureau during the past three years has been confined chiefly to the measurement of the areas of sun-spots from the observations made by Professor Peters. In the near future the measurement of spectroheliograms will be undertaken at Cambridge, and the results communicated to the Union at its next meeting.

The report of the Committee on Solar Radiation was presented by Mr. Abbot.

The report considered (*a*) The Variability of the Sun; (*b*) Atmospheric Transmission; (*c*) Light of the Sky; (*d*) Nocturnal Radiation; (*e*) The Solar Constant of Radiation; (*f*) Distribution of Radiation over the Sun's Disk.

The following summary is appended to the report:

In view of what has been reported the committee feels that the period which has elapsed since the last meeting of the Solar Union has been very productive in results on the quantity and effects of the solar radiation. In brief: The standard scale of radiation seems to be closely fixed; the mean value of the solar constant of radiation is apparently well determined; the variation of the quantity of solar radiation in association with the sun-spot numbers appears to be strongly indicated; a short irregular periodicity of the sun seems to be established; and much valuable work in connection with the distribution of radiation at different parts of the earth's surface, the

measurement of the light of the sky and of nocturnal radiation and on the connection between solar radiation and meteorology has made substantial progress.

In connection with this report a communication from Mr. Evershed was read, suggesting the possibility of studying the variation of solar radiation by comparing the light of the moon and planets with starlight.

The report of the Committee on Standards of Wave-Lengths was presented by Professor Kayser.

The accuracy of interferometer measures has been confirmed, and it has been decided that for the measurement of the tertiary standards either plane or concave gratings may be used.

It has been found that many lines vary according to the length of the arc, the part of the arc used, and the strength of the current. These variations are similar to those obtained as pressure-effects for various groups of lines at Mount Wilson. It seems necessary therefore, to define the source of light, and for future co-operation in the measurement of the tertiary standards, the committee made the following recommendations:

1. That the length of the arc should be 6 mm.

2. That the current should be 6 amperes for wave-lengths greater than 4000 Å units, and 4 amperes or less for the shorter wave-lengths.

3. That continuous current should be employed, the positive pole be above the negative, the p.d. be 2200 volts, and that the iron rods be of 7 mm diameter.

4. That the source of light examined should be a length of 2 mm at the center of the arc.

5. That only the Mount Wilson groups *a*, *b*, *c*, *d* be employed, and that for *c* and *d* the slit should be at right angles to the arc and the current should be reversed several times during the exposure.

The report of the Committee on the Classification of Stellar Spectra was presented by Professor Schlesinger.

Soon after the 1910 meeting of the Union the committee sent out the following questions:

1. At the meeting of the Committee held on Mount Wilson, there seemed to be a practically unanimous opinion that the Draper classification is the most useful that has thus far been proposed. Do you concur in this opinion? If not, what system do you prefer?

2. In any case, what objections to the Draper classification have come to your notice and what modifications do you suggest?

The report of the committee consisted chiefly in a discussion of the answers to these questions. These answers have already been published in the *Astrophysical Journal*, **33**, 260, April 1911.

The following resolutions were proposed:

1. That the Committee on the Classification of Stellar Spectra be asked to secure by co-operation the material necessary for the establishment of a system that can be recommended for permanent and universal adoption; and

2. That, pending the establishment of such a system, the use of the Draper classification be recommended in the form described in Vol. **56**, p. 66, of the *Annals of the Harvard College Observatory;* except that hereafter, in accurate classification, a zero be added to letters not followed by other numerals and that the absence of any numeral be taken to indicate only a rough classification.

The report of the Committee on the Determination of the Solar Rotation of Means of the Displacement of Lines was presented by Dr. Plaskett.

The report described the results obtained by Story and Wilson, Hubrecht, Plaskett and DeLury, and emphasized especially the discrepancies in the measures. Different observers have obtained results differing systematically by as much as 10 per cent from one another. The following resolutions were, therefore, proposed:

1. It is highly desirable to trace to their source the systematic differences that are found in the value of the solar rotation by different observers, and this investigation should take precedence of a continuation of the program adopted in 1910.

2. For this purpose study should be directed to determining the velocity at the solar equator by as many different methods as possible, and it is recommended that the ten lines chosen in 1910 in the region $\lambda 4220$–$\lambda 4280$ be used for this purpose.

3. That investigation should also be made into the personal differences that are found in measures of the same plates by different observers.

The report of the Committee on the Investigation of the Spectra of Sun-Spots was presented by Professor Fowler.

On account of the quiescent condition of the sun during the past three years the committee had very little fresh information of value. The report was devoted chiefly to the details of co-operation. The following recommendations were made:

1. That the observers should be requested to continue systematic visual observations of the umbral spectrum for at least another three years, so as to

complete a sun-spot cycle. Such observations may conveniently be restricted to a selected list of lines which has been approved by the committee.

2. That the observers be recommended to continue observations of H_α and D_3 in the neighborhood of spots, and to give attention to other phenomena mentioned in the committee's further suggestions to observers.

3. That in consideration of promises of co-operation already received, the secretary be authorized to communicate with observers possessing equipment for photographic investigations of spot-spectra with a view to organizing co-operation in the preparation of a catalogue of affected lines and possibly in other investigations.

The report of the Committee for the Organization of Eclipse Observations was presented by Count de la Baume Pluvinel. The report contained a brief description of the results obtained in recent total and annular eclipses and mentioned some plans for co-operation in the observation of the eclipse of 1914. Astronomers intending to locate in Russia should notify Dr. N. Donitch, 25 Moïka, St. Petersburg, and state the weight of their apparatus.

The report of the Committee on Work with the Spectroheliograph was presented by Professor Slocum.

As a part of the report accounts of the progress of work at the various observatories were given by Riccò, St. John, Slocum, Chrètien, Donitch, Ascarza, Butler, and Kempf.

The following recommendations of the cómmittee were adopted:

1. That a systematic comparison be made of the results from different types of spectroheliograms, as given by instruments of varied form and dispersive power, utilizing as many observations as possible.

2. That the observatories of Coimbra, Nice, and Starya Doubossary, Bessarabia, South Russia, having now acquired spectroheliographs, should be added to our list, and that their directors be invited to send delegates to our meetings.

3. That spectroheliographs of high dispersion capable of recording the details of the higher atmosphere with the K_3 or H_α lines, combined with image-forming apparatus of long focus, should be installed wherever possible.

4. That the "*spectro-enregistreur des vitesses*" for the *radial* velocities be recommended especially for use with the hydrogen and calcium lines.

5. That the Union express its hearty gratification with regard to the reported possibility that the memorial to Secchi may take the form of a tower telescope in the vicinity of Reggio (Emilia), for the general study of the solar atmosphere, and that this undertaking be supported as a desirable addition to the equipment for solar observations in northern latitudes.

6. That the title of the committee be changed to the more general name "The Committee on Solar Atmosphere," so as to include and to unify all the observations on the solar atmosphere, visual and photographic, except those associated with eclipses.

It is suggested that this committee may then be composed of two subcommittees: the *first* to be devoted to visual observations of prominences and related phenomena; the *second*, to photography of the forms, and determination of the velocities manifested in the solar atmosphere, both of the disk and limb.

The committee wishes to record that it is recognized that for many years there has been in existence an active and efficient organization for co-operation in the visual observations of prominences, and it is hoped that by its inclusion within this Committee on Solar Atmosphere, this and other similar bodies may be induced to join in the work of the Union.

After the adoption of the last recommendation, the subcommittee for the visual observation of prominences was appointed with Professor Riccò as chairman and Father Cortie as secretary. This committee held a meeting and voted to present the following recommendations, all of which were adopted:

1. That observers be recommended to observe not only the height of prominences, but the arc they cover on the sun's limb and to express their results for each prominence as profile areas.

2. That an area covered by an arc one degree (of the sun's limb) in length and one second (of arc of the celestial sphere) in height be adopted as the conventional unit of profile area; and that it be called the prominence unit.

3. That the limiting height for statistics of frequency be $30''$.

4. That the position angles round the sun's limb be recorded in the direction N.E.S.W. from the apparent north point.

5. That, if possible, the height of the chromosphere be measured at every 45°, and at other points where it is notably above or below its normal level.

6. That prominences be classified into very high, high, moderately high, faint, very faint.

In accordance with the custom of the Union there were no formal papers, but the following special reports were presented:

Buisson, Standards of Wave-Lengths.
Deslandres, Solar Work at Meudon.
Riccò, Statistics of Solar Prominences.
Julius, Refraction of Light in Passing through Whirling Gases.
Julius, Interpretation of Sun-Spots.
St. John, Radial Motion in Sun-Spots.
St. John, Rotation of the Sun as Determined by Different Lines.

Hale (read by St. John), General Magnetic Field of the Sun.

Hemsalech, Influence of a Transverse Magnetic Field on the Aspect and Spectrum of a Calcium Spark in Hydrogen.

Störmer, Observations of the Aurora.

Störmer, Interpretation of Solar Phenomena.

Duffield, Conditions in Australia in Regard to a New Government Solar Observatory.

The following are the committees of the Union as announced at the Bonn meeting:

1. On Standards of Wave-Lengths:
   Kayser (*chairman*), Ames, Burns, Buisson, Fabry, Goos, Michelson, Paschen, Perot, St. John.
2. On the Measurement of Solar Radiation:
   Violle (*chairman*), Abbot (*secretary*), Callendar, Chistoni, Evershed, Julius, Pringsheim, Schuster.
3. On Solar Atmosphere:
   a) Visual (prominences):
   Riccò (*chairman*), Cortie (*secretary*), Ascarza, Butler, Chevalier, Deslandres, Evershed, Fenyi, Fowler, Jiminez, Kempf, Tringali, Whitelow.
   b) Photographic (using spectroheliograph, *enregistreur des vitesses*, spectrograph):
   Hale (*chairman*), Chrètien, Cirera, Costa Lobo, Deslandres, Donitch, Evershed, Frost, Iñiguez, Kempf, W. J. Lockyer, Newall, Riccò, Slocum, St. John.
4. On the Investigation of the Spectra of Sun-Spots:
   Newall (*chairman*), Fowler (*secretary*), Adams, Belopolsky, Cortie, Deslandres, Dyson, Evershed, Fox, Hale, N. Lockyer, W. Mitchell, Plaskett, Wolfer.
5. On the Organization of Eclipse Observations:
   N. Lockyer (*chairman*), de la Baume Pluvinel (*secretary*), Blumbach, Campbell, Cirera, Donitch, Fowler, Hills, Kempf, Riccò, Strömgren, Turner.
6. On the Determination of the Solar Rotation by Means of the Displacement of Lines:
   Dunèr (*chairman*), Adams (*secretary*), Belopolsky, Deslandres, Dyson, Halm, Hubrecht, Newall, Perot, Plaskett, Samson, Schlesinger.
7. On the Classification of Stellar Spectra:
   E. C. Pickering, (*chairman*), Schlesinger (*secretary*), Adams, Belopolsky, Campbell, Miss Cannon, Fowler, Frost, Hale, Hamy, Hartmann, Hertzsprung, Iñiguez, Kapteyn, Küstner, Newall, Plaskett, Russell, Schwarzschild.

F. SLOCUM

The following astronomers and physicists were present:

C. G. Abbot, Smithsonian Astrophysical Observatory, Washington, D.C.
Sir W. de W. Abney, Atherstone, England.
Miss L. B. Allen, Whitin Observatory, Wellesley, Mass.
J. S. Ames, Johns Hopkins University, Baltimore, Md.
V. F. Ascarza, Observatorio, Madrid, Spain.
O. Backlund, Observatoire de Poulkova, Poulkova, Russia.
S. I. Bailey, Harvard College Observatory, Cambridge, Mass.
B. Baillund, Observatoire de Paris, Paris, France.
J. Baillund, Observatoire de Paris, Paris, France.
A. Belopolsky, Observatoire de Poulkova, Poulkova, Russia.
F. J. Blumbach, St. Petersburg, Russia.
J. Bosler, Observatoire de Meudon, Meudon, France.
H. Buisson, Université d'Aix-Marseille, Marseille, France.
K. Burns, Bureau of Standards, Washington, D.C.
C. P. Butler, Solar Physics Observatory, Cambridge, England.
W. W. Campbell, Lick Observatory, Mount Hamilton, Cal.
Miss A. J. Cannon, Harvard College Observatory, Cambridge, Mass.
H. Chrètien, Observatoire de Nice, Nice, France.
A. L. Cortie, S. J., Stonyhurst College Observatory, Lancashire, England.
A. Cotton, École Normale Supérieure, Paris, France.
F. Croze, Paris, France.
H. Deslandres, Observatoire de Meudon, Meudon, France.
N. Donitch, Observatoire de l'Université, St. Petersburg, Russia.
C. L. Doolittle, Flower Observatory, Philadelphia, Pa.
W. G. Duffield, London, England.
F. W. Dyson, Royal Observatory, Greenwich, England.
G. Eberhard, Astrophysikalisches Observatorium, Potsdam, Germany.
A. S. Eddington, Cambridge University, Cambridge, England.
P. Eversheim, Universität, Bonn, Germany.
E. Fayet, Observatoire de Nice, Nice, France.
A. Fowler, Imperial College of Science and Technology, South Kensington, London, England.
R. Furuhjelm, Astronomisches Observatorium, Helsingfors, Finland.
Prince B. Galitzin, Observatoire Physique Central Nicolas, St. Petersburg, Russia.
H. Giebeler, Universität, Bonn, Germany.
C. H. Gingrich, Carleton College, Northfield, Minn.
L. C. Glaser, Berlin, Germany.
F. Goos, Physikalisches Staatslaboratorium, Hamburg, Germany.
L. Grebe, Universität, Bonn, Germany.
J. G. Hagen, S. J., Vatican Observatory, Rome, Italy.
J. Hartmann, Königliche Sternwarte, Göttingen, Germany.

K. Haussmann, Technische Hochschule, Aachen, Germany.
D. E. A. Hemsalech, Paris, France.
E. Hertzsprung, Astrophysikalisches Observatorium, Potsdam, Germany.
J. v. Hepperger, K. K. Sternwarte, Vienna, Austria.
Major E. H. Hills, London, England.
O. Holz, Universität, Bonn, Germany.
J. Hopmann.
J. B. Hubrecht, Knutsford, England.
L. Janicki, Physikalische Technische Reichsanstalt.
P. Jiménez, Observatorio Astronomico, Madrid, Spain.
W. H. Julius, University, Utrecht, Holland.
H. Kayser, Universität, Bonn, Germany.
P. Kempf, Astrophysikalisches Observatorium, Potsdam, Germany.
H. Knox-Shaw, Helwan Observatory, Helwan, Egypt.
H. Konen, Physikalisches Institut, Münster, Germany.
F. Küstner, Königliche Sternwarte, Bonn, Germany.
H. Ludendorff, Astrophysikalisches Observatorium, Potsdam, Germany.
C. Mönnichmeyer, Königliche Sternwarte, Bonn, Germany.
W. Michelson, Moscow, Russia.
E. L. Nichols, Cornell University, Ithaca, N.Y.
J. W. Nicholson, Cambridge University, Cambridge, England.
F. Nierhoff, Universität, Bonn, Germany.
Baron v. d. Pahlen, Caputh bei Potsdam, Germany.
J. A. Parkhurst, Yerkes Observatory, Williams Bay, Wis.
F. Paschen, Universität, Tübingen, Germany.
A. Pflüger, Universität, Bonn, Germany.
E. C. Pickering, Harvard College Observatory, Cambridge, Mass.
V. d. Plaats, Utrecht, Holland.
J. S. Plaskett, Dominion Observatory, Ottawa, Canada.
H. C. Plummer, Dunsink, Royal Observatory, Dublin, Ireland.
Count A. de la Baume Pluvinel, Rué de la Baume, Paris, France.
E. Pringsheim, Universität, Breslau, Germany.
A. Riccò, Osservatorio Astrofisico, Catania, Sicily.
G. B. Rizzo, Regia Università, Messina, Italy.
C. Runge, Universität, Göttingen, Germany.
H. N. Russell, Halsted Observatory, Princeton, N.J.
C. E. St. John, Mount Wilson Solar Observatory, Pasadena, Cal.
P. Salet, Observatoire de Paris, Paris, France.
R. A. Sampson, Royal Observatory, Edinburgh, Scotland.
F. Schlesinger, Allegheny Observatory, Allegheny, Pa.
K. Schwarzschild, Astrophysikalisches Observatorium, Potsdam, Germany.
H. Shapley, Halsted Observatory, Princeton, N.J.
F. Slocum, Yerkes Observatory, Williams Bay, Wis.

J. Stebbins, University of Illinois, Urbana, Ill.
C. Störmer, Universitet, Christiania, Norway.
F. J. M. Stratton, Cambridge University, Cambridge, England.
E. Strömgren, Universitets-Observatoriet, Copenhagen, Denmark.
P. Stroobant, Observatoire Royal de Belgique, Uccle, Belgium.
H. H. Turner, University Observatory, Oxford, England.
G. Van Biesbroeck, Observatoire Royal de Belgique, Uccle, Belgium.
W. Voigt, Universität, Göttingen, Germany.
C. de Watteville, Paris, France.
E. Weiss, Vienna, Austria.
M. E. T. Whitelow, Southport, England.
Miss S. F. Whiting, Whitin Observatory, Wellesley, Mass.
M. Wolf, Grossherzogliche Sternwarte, Heidelberg, Germany.
W. Zurhellen, Königliche Sternwarte, Neu Babelsberg bei Berlin, Germany.

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ON AN AURORAL EXPEDITION TO BOSSEKOP IN THE SPRING OF 1913

By CARL STÖRMER

The following is a short account of a new auroral expedition which I made to Bossekop in the spring of 1913 for the purpose of completing the results of my expedition[1] to the same place in 1910.

My assistant was the meteorologist, Bernt Johannes Birkeland, who also went with me in 1910, and is going with Roald Amundsen's expedition over the North Polar basin.

The purpose of the expedition was mainly to obtain more accurate, more numerous auroral photographs for the determination of the form of aurora, and its height and situation in space, and further to experiment with objective-prism photographing and the taking of cinematograph films.

Our preparations and equipment were on the whole the same as in 1910; but the following improvements, based upon experience gained on that expedition, were carried out:

The cameras were furnished with an arrangement whereby a photograph of an illuminated watch-face was taken on the plate exactly simultaneously with the aurora. The time could then be read from the photograph, and also the exposure by the sector

[1] See "Bericht über eine Expedition nach Bossekop zwecks photographischer Aufnahmen und Höhenmessungen von Nordlichtern," mit 57 Figuren im Text und 88 Tafeln, *Videnskabsselskabets Skrifter, Math.-Naturv. Klasse 1911*, No. 17, Christiania.

described by the second-hand. This improvement I had already employed in photographing aurora in Christiania in the winter of 1910–1911.

In order to avoid the waste of time in changing plates in a dark room, each station, in addition to 40 cassettes, was furnished with changing-boxes in which the plates could be changed in the open air. Thanks to this improvement, it was possible on some evenings to take more than 80 simultaneous photographs at the two stations.

In order to have the arms at liberty, the following improvement in the telephone arrangement was made: The microphone and receiver were fixed to the chest and head, and connected with the field telephone apparatus by a cord 4 meters in length. In this way it became possible to utilize more fully the brief moments during which the aurora displayed its greatest intensity.

For the purpose of obtaining reliable parallaxes, a base of 27½ kilometers was chosen, as against 4½ kilometers in 1910. The station at which Birkeland took up his quarters was Store Korsnes, the other was Bossekop. As assistant at Bossekop I had engaged Sergeant Ottem. The direction from Bossekop to Store Korsnes was almost due north.

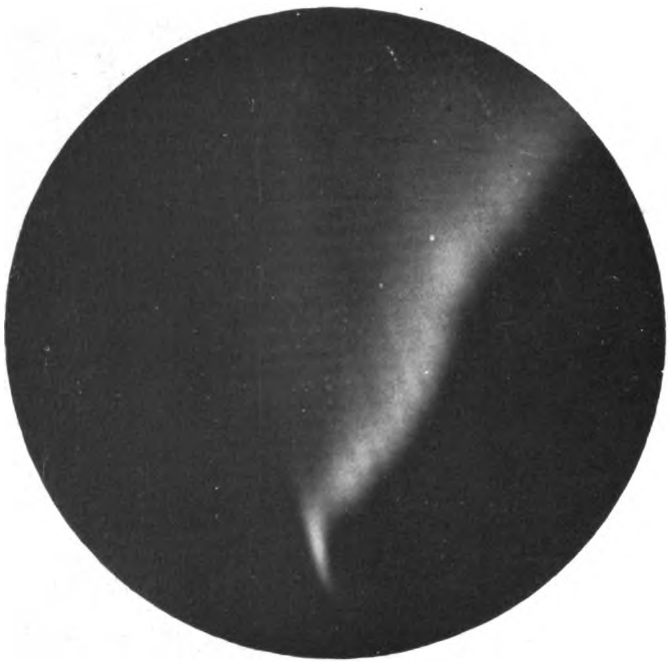
Through the courtesy of the Telegraph Department, the state telephone line from Bossekop to Korsnes was placed at our disposal every night from 7:30 P.M.

As a result of these arrangements, we succeeded in one month in taking the following pairs (see table on p. 313) of simultaneous auroral photographs at Bossekop and Korsnes.

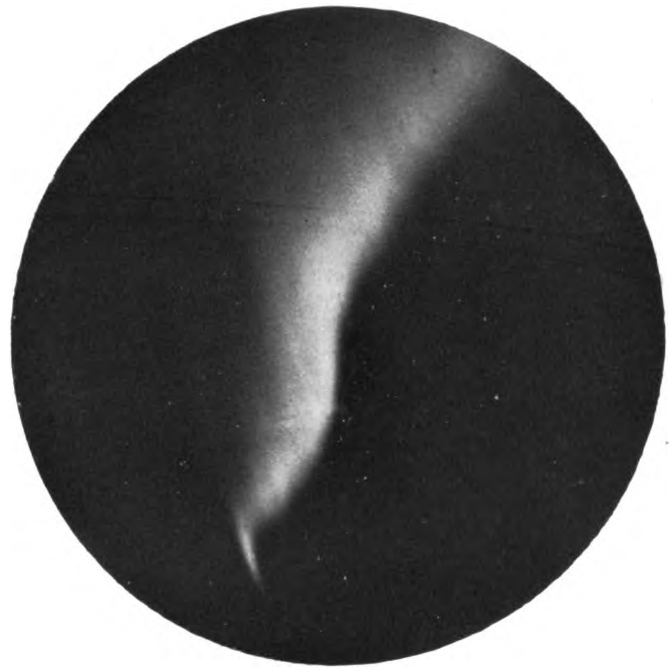
On the 6 best evenings, March 11, 14, 15, 29, and 30, and April 1, the weather was clear and the aurora vivid and continuous, so that we were able to make use of every chance.

The parallaxes, thanks to the large base, were very distinct, as a rule between 5 and 15 degrees, and the large number of photographs—447 pairs as against 44 in 1910—gives very much more certain and complete results than on that occasion. If we reckon about 10 measurements to each photograph, these will give more than 4,000 reliable determinations of height. All important forms of aurora were photographed, and there are long series of developments.

PLATE VI



Photographed from Bossekop

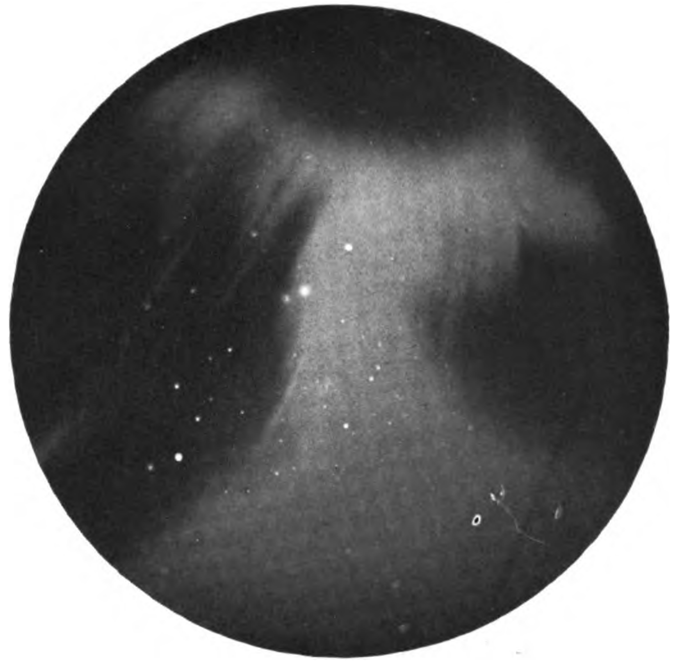


Photographed from Store Korsnes

AURORAL DRAPERY WITH *Gemini*, MARCH 11, 1913, $12^h 33^m$. EXPOSURE 3 SEC.

PLATE VII

Photographed from Store Korsnes

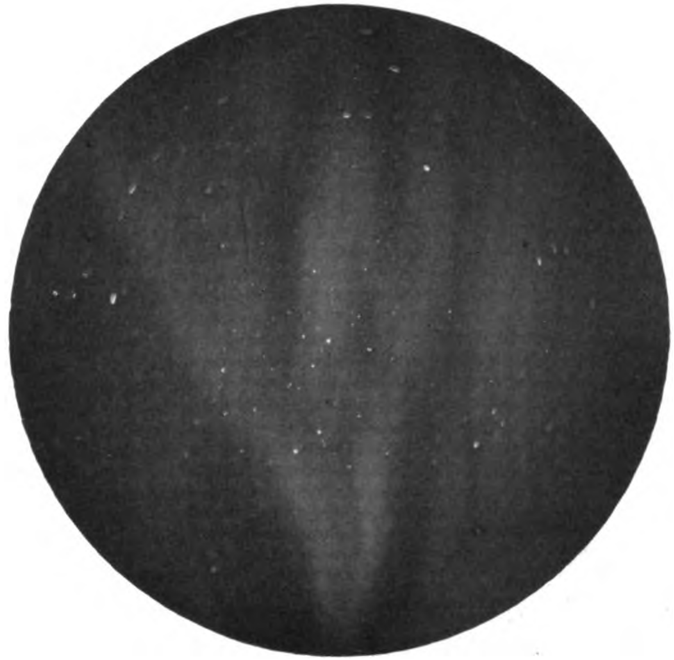


Photographed from Bossekop

AURORA IN THE FORM OF A LUMINOUS TRANQUIL SURFACE, MARCH 11, 1913, 12^h53^m. IN THE BACKGROUND ARE *Arcturus* AND *Gemma*

PLATE VIII

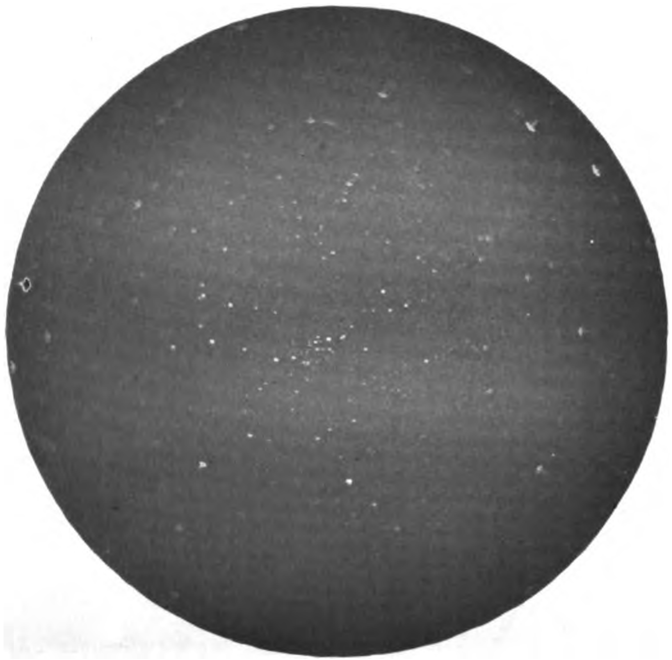
Photographed from Store Korsnes



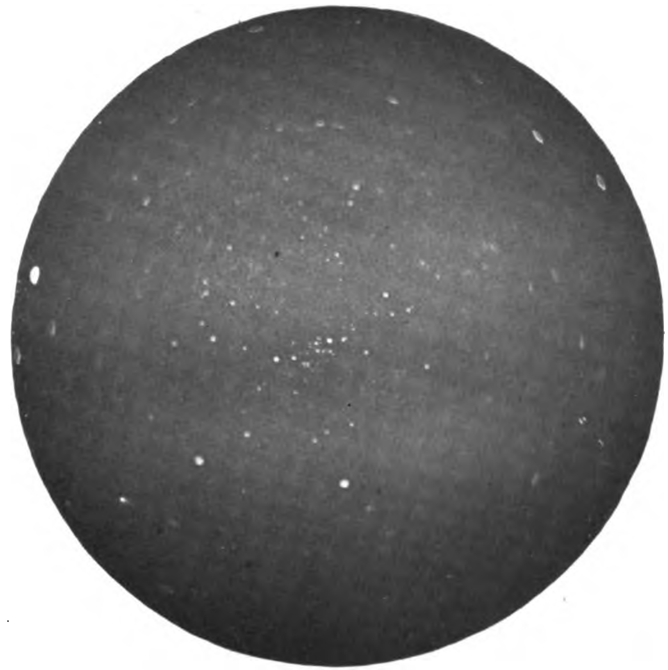
Photographed from Bossekop

AURORA WITH *Vega*, MARCH 30, 1913, $10^h 20^m$

PLATE IX



Photographed from Store Korsnes



Photographed from Bossekop

EXCEEDINGLY FAINT, HOMOGENEOUS AURORAL ARCS, WITH *Perseus*, APRIL 1, 1913, 12^h5^m

Some of the photographs are here reproduced (Plates VI–IX), enlarged about $2\frac{1}{4}$ times, one degree answering to 2 mm in the photograph. The time is Central European time and reckoned from 0^h to 24^h, 0^h answering to 12 noon.

Day	Number of Pairs Taken	Successful
February 28	14	0
March 3	38	19
" 4	23	9
" 6	7	1
" 11	86	58
" 14	81	54
" 15	81	72
" 16	8	2
" 17	14	7
" 18	5	5
" 21	23	20
" 22	20	12
" 23	1	1
" 24	6	6
" 28	5	3
" 29	83	64
" 30	71	62
April 1	70	52
Total	636	447

With an objective-prism we succeeded in taking some photographs simultaneously with the auroral photographs, on which are seen stellar spectra and some views of the aurora lying side by side, answering to various spectral lines. The prism[1] had an angle of 60° and was placed in front of the kinostigmatic objective, on the principle already mentioned in my "Bericht." A systematic employment of this method will be of great importance to the study of the highest strata of the atmosphere.

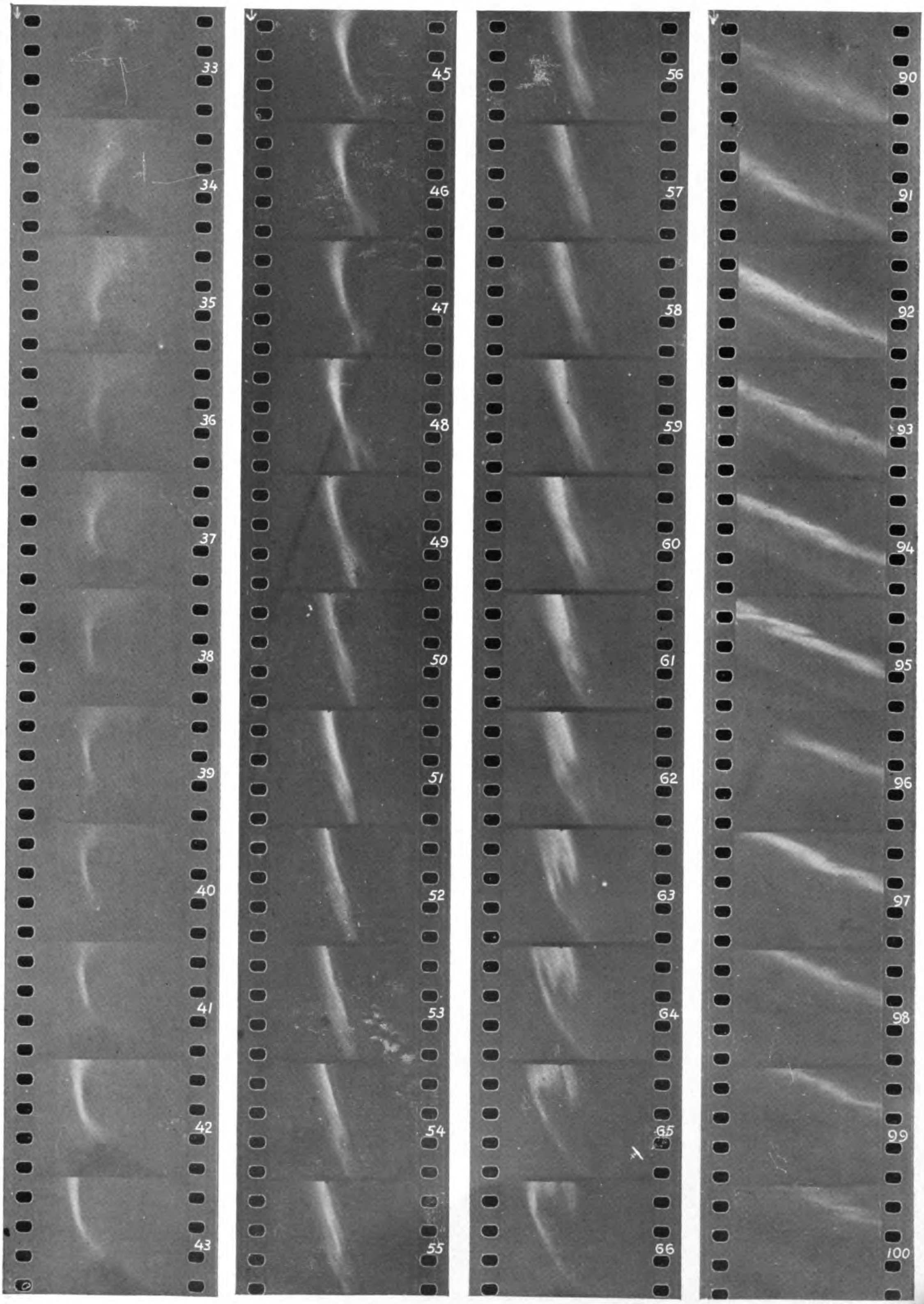
Most of the cinematograph attempts were failures, as the film (*Lumière*) was not as a rule affected by an exposure of less than 2 seconds. It was only with very intense aurora that we succeeded in getting good photographs with an exposure of about 1 second and with about 2 seconds' interval between the photographs. Two

[1] With regard to the kind of glass that would be best for the purpose, I received valuable information from Dr. Slipher when visiting the Flagstaff Observatory in the summer of 1912.

or three such series were taken, thus proving the utility of the cinematograph both for taking photographs and for registering rapid changes. Parts of a film of about 100 pictures are here given (Plate X), taken on the night between April 8 and 9, of an aurora in the west. Each picture was exposed from 3 to 5 seconds. The figures give the numbers in chronological order.

The working-up of the matter collected during the expedition will be the subject of a subsequent detailed account.

PLATE X



CINEMATOGRAPH PICTURES OF AURORA ON APRIL 8, 1913, BETWEEN 12^h AND $12^h 15^m$, BOSSEKOP.

A STUDY OF THE RELATION OF ARC AND SPARK LINES BY MEANS OF THE TUBE-ARC[1]

By ARTHUR S. KING

In a recent paper,[2] the writer described the peculiarities in the spectra given by a special form of vacuum arc. The graphite tube employed in a tube resistance furnace was forced to high incandescence and made to burn through. An arc formed between the two sections of the tube in which currents as high as 800 amperes sometimes passed at a potential of about 30 volts. When the interior of the tube was observed axially, with titanium present, the spectrum given by this arc showed a predominance of those lines which are stronger in the spark than in the arc. By projecting an image of the interior of the tube on the slit of a plane-grating spectrograph, the strength of the spectrum lines was found to vary in different parts of the cross-section, the titanium enhanced lines being relatively strong in the center of the tube, while the lines characteristic of the arc showed most strongly near the wall. A strong line of carbon, λ 4267, usually appearing only in the spark, was very intense in the center of the tube and weak near the wall.

This source, which may appropriately be named the "tube-arc," has been used in further experiments which have confirmed and extended the previous results. In addition to the spectra of several metals and of carbon, the spectrum of hydrogen has been included in the later investigation, and the results render it possible to form a gradation among the arc and spark lines of these elements according to the degree in which they respond to an excitation which is clearly favorable to the production of spark lines. Some light is also thrown on the probable character of the radiation produced in this way.

[1] *Contributions from the Mount Wilson Solar Observatory*, No. 73.

[2] *Contributions from the Mount Wilson Solar Observatory*, No. 65; *Astrophysical Journal*, 37, 119, 1913.

DESCRIPTION OF EXPERIMENTS

Following the preliminary experiments already reported, the same method was employed at first to examine the spectra of different elements and to cover a greater range of wave-length. The vertical plane-grating spectrograph was used as before, with an objective of 30 ft. (9.1 m) focal length. An image of the interior of the furnace tube was projected on the slit, so that the latter passed across the horizontal diameter of the tube's image. The spectrum line photographed then registered the condition of the radiation for the given wave-length along this diameter. A number of second-order spectra for the region from λ 3850 to λ 4600, supplemented by some in the first order extending as far as λ 5400, confirmed the former results that the titanium enhanced lines maintained their strength with little change from center to wall of the tube, while the arc lines were strongest near the wall. The carbon spark lines at λ 3919 and λ 3921 (the former not given in the wave-length tables of Exner and Haschek, probably on account of its faintness) showed the same strength at the center of the tube and weakness near the wall which had been previously observed for λ 4267.

In the course of these experiments, a small spectrograph containing a concave grating of 1 meter radius was occasionally used to make photographs simultaneously with those of the large-scale instrument, the two windows at opposite ends of the furnace chamber being utilized in this way. These small-scale photographs showed the state of the tube-arc spectrum in the ultra-violet, but a fact of special interest was the appearance of the strong lines of hydrogen, in one case five members of the series from H_α to H_ϵ inclusive being photographed. The chief supply of hydrogen in this case was probably gas absorbed in the tube of Acheson graphite, since the air was pumped out to a pressure of less than 2 cm of mercury. The fact that the hydrogen spectrum appears thus in an arc at low voltage with high current is to be considered in connection with the other instances in which these lines have been observed in the arc, beginning with the experiment of Liveing and Dewar[1]

[1] *Proceedings of the Royal Society*, **35**, 74, 1883.

in which the hydrogen spectrum appeared when water was dropped into a carbon arc.

In order to examine the behavior of the hydrogen lines in different parts of the tube's cross-section, H_α was then photographed with the long slit of the plane-grating spectrograph along the horizontal diameter of the image of the tube, the first order of the grating being used. It was possible to connect the phenomena for H_α with those already observed for the tube-arc spectrum in the blue and violet on account of the presence of the carbon spark lines, $\lambda\lambda$ 6578 and 6583, close to H_α and a number of strong titanium arc lines in the same region. The experiments were carried out usually with a little titanium metal in the tube, though sometimes the tube was empty. In some cases the chamber contained air pumped to a low pressure, but stronger hydrogen lines were obtained when the furnace chamber was filled with purified hydrogen at from 2 to 5 cm pressure, the chamber being flushed at least three times with hydrogen before the tube-arc was operated. The intensity gradation of H_α from center to wall of the tube under these conditions proved to be the same as that of the adjacent carbon spark lines, the maximum intensity being at the center of the tube, with a gradual decrease toward the wall, agreeing perfectly with the appearance of the carbon spark lines in the blue and violet. It is the structure illustrated by the carbon line λ 4267 in the second plate of the previous paper. In striking contrast to these lines, the same plates showed a number of titanium arc lines having the usual structure observed in the tube-arc, weak in the center of the tube and strong near the wall.

An extended series of experiments was then taken up with the slit of the spectrograph along the vertical diameter of the image of the tube, which was of interest because the burning apart of the tube was often more violent at the bottom than at the top, especially when the tube was inclosed in the graphite jacket to be described later. I attribute this difference to the fact that the arc vapors from the top of the tube were carried upward into the cool space above, while the arc at the bottom of the tube had above it the hot vapor of the tube's interior. The conditions were thus favorable for a more violent vaporization of the carbon below than above,

and the effect of this appeared at once when the spectrograph was rotated so as to examine the state of the radiation along the vertical diameter of the tube. The maximum intensity for H_α and the carbon spark lines was now seen to be below the center of the tube, roughly one-third of the way between bottom and top. The intensity shaded off rapidly toward the bottom and slowly toward the top, the condition that the region near the wall is relatively unfavorable for these lines holding as for the observations along the horizontal diameter. The appearance of H_α and its neighboring carbon lines when photographed in this way is shown in Plate XI.

These experiments threw light on the effects previously obtained, showing that the maximum at the center of the horizontal diameter was due to its proximity to the true position of strongest radiation, situated slightly below the center. The standard appearance in the tube-arc was also given for lines which may be fairly considered as typical of spark radiation.

The next step in the investigation was the study of the arc and enhanced lines of a number of elements as given by the tube-arc, in order to compare the intensity distribution of such lines along the diameter of the tube with that of the hydrogen and carbon lines.

Attempts were made early in the work to obtain the magnesium spectrum, on account of the importance of the spark line λ 4481, but at first no trace of this line appeared, even with a large amount of magnesium in the middle portion of the tube. I could account for this only on the ground that since magnesium is very volatile, the intense heat in the thin part of the tube vaporized all of the metal present at the point where the break eventually occurred, and the vapor passed into cooler regions, so that when the tube burned apart the arc which formed did not contain enough of this vapor to show the spectrum in the short exposure. At any rate, the difficulty disappeared when magnesium vapor was supplied from without the tube, as was done by jacketing the middle portion of the furnace tube by a split graphite tube 10 cm long. When the latter was supported from beneath and the two halves placed together, it inclosed the thin portion of the furnace tube with a clearance of about 5 mm all around. A quantity of powdered magnesium was then placed in the jacket tube just below the place

where the arc would form, this being located by filing the tube still thinner at this point. This adaptation of the principle of the Moissan arc-furnace was effective. The intense heating of the furnace tube before burning apart served to vaporize the metal in the jacket tube, so that when the arc formed, the vapor in the jacket was ready to flow into the break. The magnesium spectrum then appeared with great brilliancy, λ 4481 being the strongest line in the blue region. Iron also gave a richer spectrum when some of the metal was placed in the jacket as well as in the tube.

The furnace tube with graphite jacket is shown in section in Fig. 1, the ends of the tube, which are clamped in vertical contact blocks, being omitted from the figure. The arc was made to

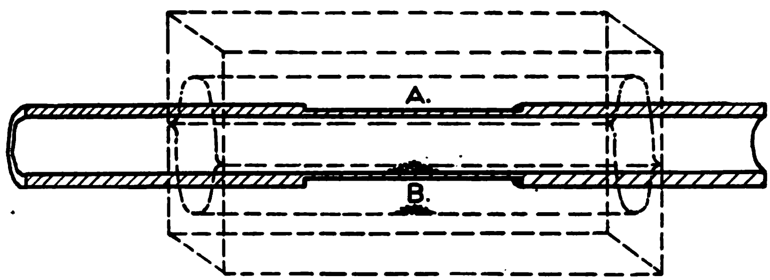


FIG. 1.—Arrangement of furnace tube and graphite jacket for tube-arc experiments.

form around the periphery of the tube at A B, the portion at B burning apart farther than at A. Aside from supplying vapor in the case of difficult metals, the jacket increased the difference between the burning at top and bottom of the tube, and seemed to enable the arc to hold longer than when no jacket was used. The duration of the arc varied greatly in different experiments. It usually burned from 5 to 15 seconds, which was quite sufficient for a strong photograph even with the large scale of spectrum used; but sometimes the arc ceased almost at once, and in one extreme case burned for 30 seconds. I have concluded from such modifications of the method as have been made thus far (the experiments being tedious on account of the labor of preparing the apparatus for each run) that in addition to a low pressure, tubes graphitized only to a certain degree give the best results for the

action of the tube-arc. Tubes of very smooth graphite did not hold the arc as well as those of which the material was somewhat gritty. Trials with carbon tubes have resulted in failures, but carbon can perhaps be made to serve if the required adjustment of size and impressed voltage are determined by extended tests.

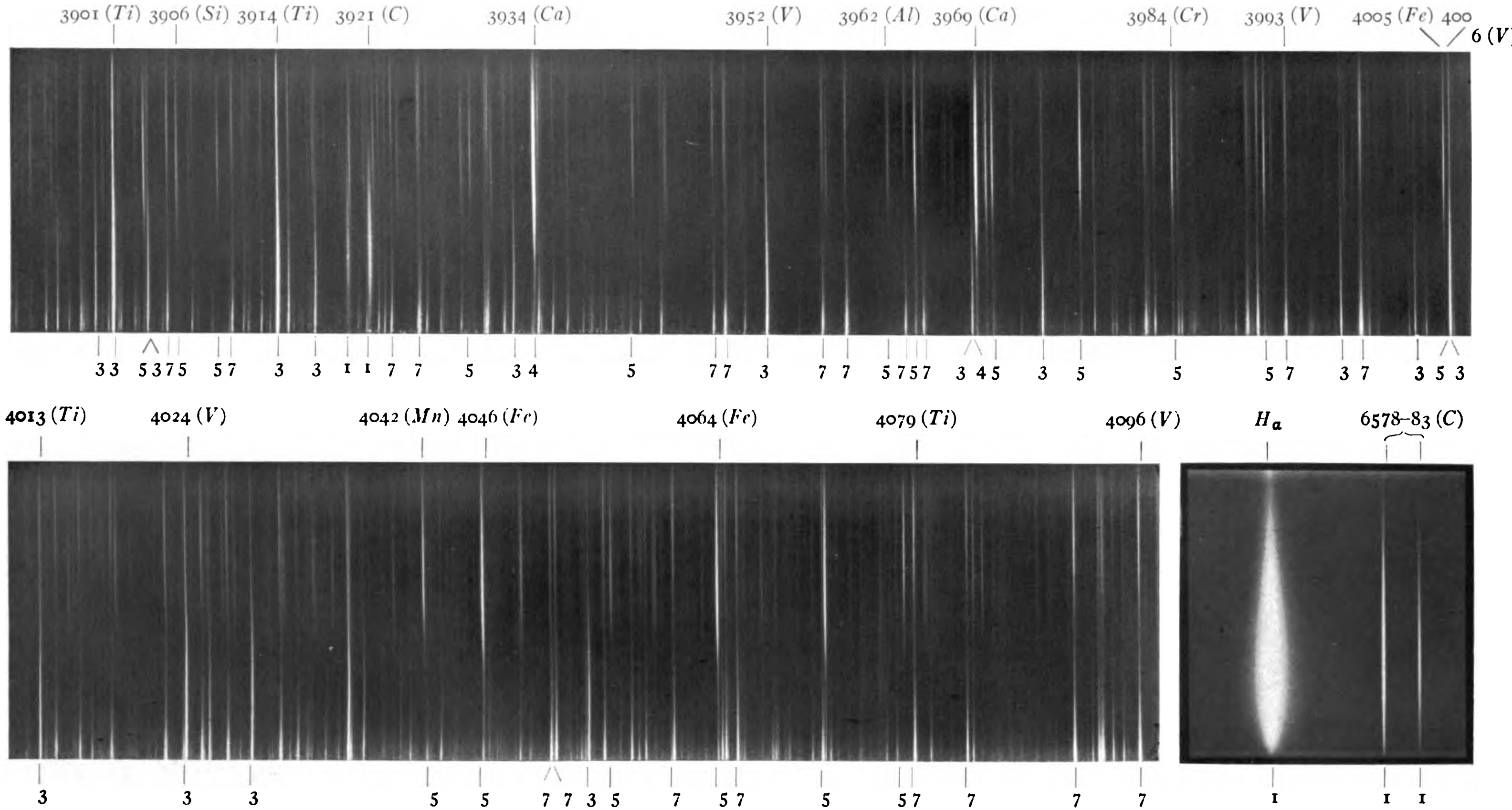
REGIONS OF SPECTRUM STUDIED

The results to be discussed are based on a set of fifty plates taken since those reported in the earlier paper. For about one-fourth of these, films were taken simultaneously with the 1-meter concave grating. Second order photographs were taken with the plane grating on a scale of approximately 0.9 Å per mm for the range from λ 3880 to λ 4280 and from λ 4240 to λ 4640. The carbon spark line λ 4267 occurred in both these sections and was useful for reference. An extended study was made of these regions and also of the first-order red including H_α. A few plates were made of the first-order green-yellow from λ 4800 to λ 5600, and two photographs were taken with the second order of the grating and an objective of 13 ft. (4 m) focal length. This gave greater brightness and nearly the same scale as the first order at 30 ft., the photographs being made chiefly to compare the behavior of λ 4481 of magnesium with the strong arc triplet $\lambda\lambda$ 3830, 3832, 3838.

GENERAL CHARACTER OF THE PHENOMENA

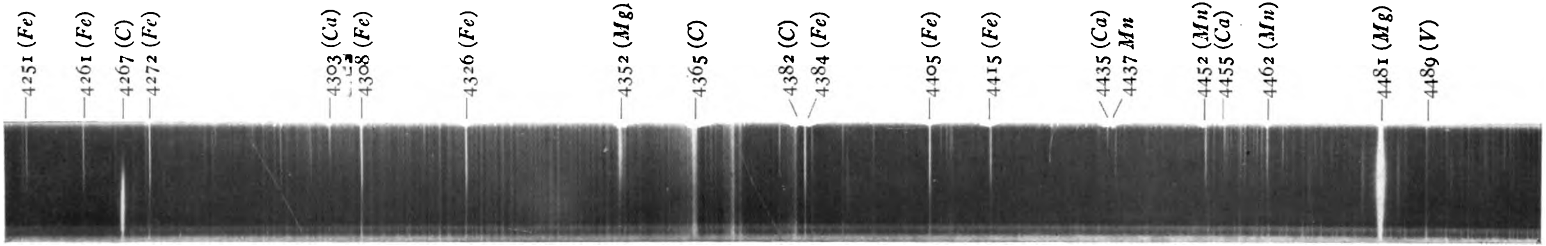
Photographs made with the spectrograph arranged so that the long slit passed along the vertical diameter of the image of the tube's interior present a very peculiar appearance, owing to the fact that different regions of the tube's cross-section are especially favorable for the production of certain groups of lines. The situation will be made clear by a reference to the spectra of Plates XI and XII, supplemented by the curves of Fig. 2. Plate XI shows, in two sections, a stretch of spectrum in the violet. Plate XII, *a* shows the relative behavior of the lines of several elements and especially the development of λ 4481 of magnesium. A number of typical lines of several elements are marked in the margin of each. In addition a reproduction is given in Plate XI of H_α and the adjacent carbon spark lines $\lambda\lambda$ 6578 and 6583, taken in the

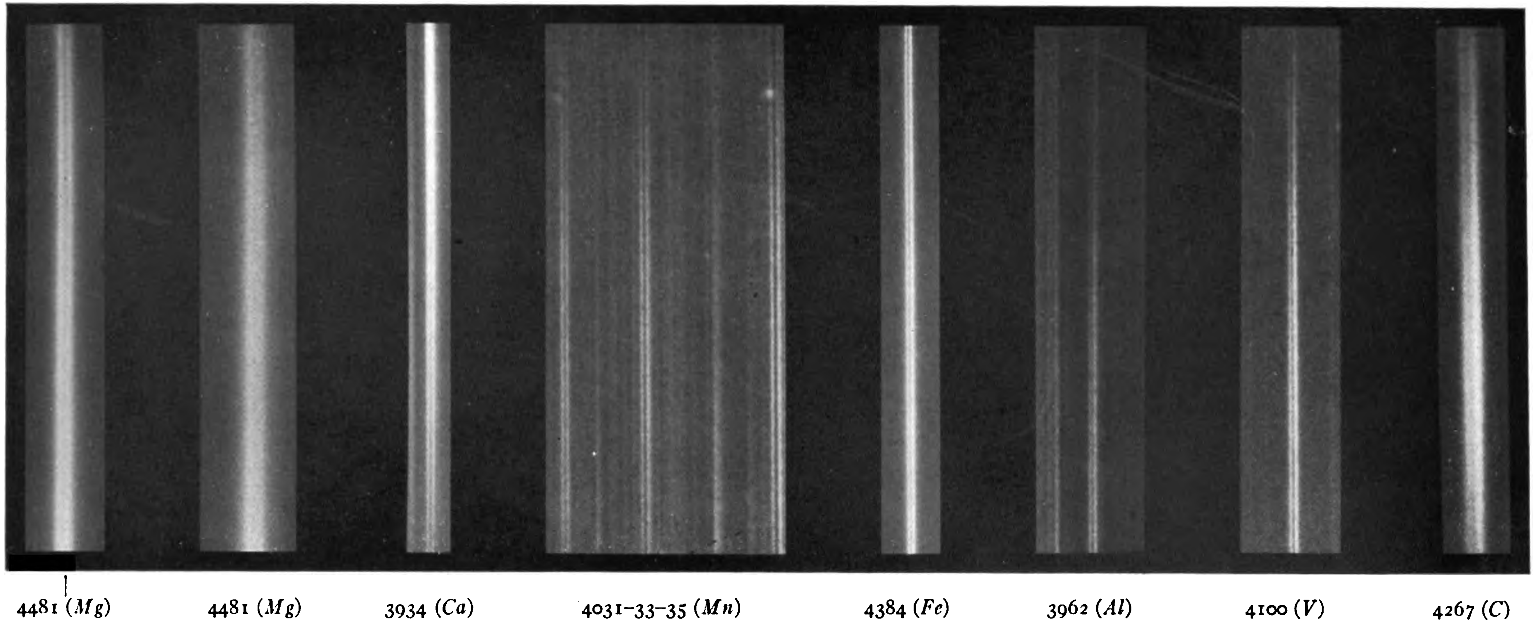
PLATE XI



Spectrum of the tube-arc, with spectrograph slit along the vertical diameter of the tube's image, showing arc and enhanced lines of various metals, also lines of hydrogen and carbon. The numbers below refer to the groups on p. 323.

PLATE XII

a


b


a. Spectrum of the tube-arc, with spectrograph slit along the vertical diameter of the tube's image, showing the intensity gradation from center to wall of the tube of λ 4481 of magnesium compared with that of λ 4267 of carbon and of the arc lines of magnesium iron, manganese, calcium, and vanadium.

b. Enlargements of tube-arc lines, showing structure.

same way. The structure, as regards position of maximum strength, is seen to be the same for the hydrogen and carbon lines and the fact that the violet and blue carbon lines $\lambda\lambda$ 3919, 3921, and 4267 show their maxima at about the same height as those in the red establishes the form of this type of spark line. An attempt to represent this graphically is made in Fig. 2, the full-line curve from left to right following the intensity of the line from bottom to top, as given by the tube-arc. λ 4481 of magnesium shows its greatest intensity at about the same height as do the hydrogen and carbon lines, but weakens toward the wall of the tube above and below more slowly than these. The spark lines of lead, $\lambda\lambda$ 4245 and 4387, are similar. The gradation in intensity for these lines

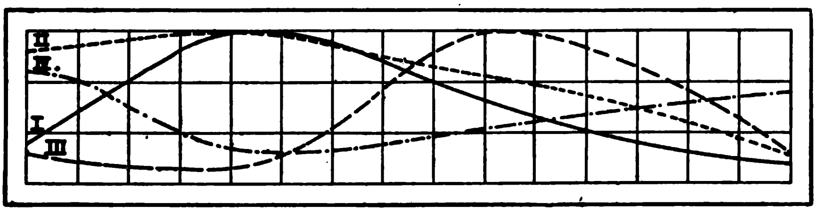


FIG. 2.—Curves showing intensity gradation of various groups of tube-arc lines from bottom (at left of figure) to top of the furnace tube. I, Groups 1, 2; II, Group 3; III, Groups 4, 5, 6; IV, Group 7.

is intermediate between that of the hydrogen and carbon lines and that of the enhanced lines of titanium, vanadium, iron, chromium, and manganese, which show a preference for the position which seems to be that of strongest spark radiation but are given with slightly diminished intensity at the bottom of the tube, where the arc burns with greatest intensity. The latter fade rapidly toward the top of the tube, the weaker lines of this class not showing in the upper half. Their intensity change is represented by Curve II. A distribution of intensity in strong contrast to the last class is shown by the arc lines of iron, chromium, magnesium, manganese, aluminum, calcium, strontium, barium, silicon (λ 3905.71), and tin (λ 4524.90). These lines are strongest slightly above the center of the tube. They weaken rapidly below the center, where the enhanced lines are strongest, and slowly toward the top of the tube (Curve III). The variability does not end here. The arc

lines of titanium and vanadium are distinctly in a class by themselves among the elements so far observed. Their maximum intensity follows the location of the strongest arc discharge, these lines being very strong at the bottom of the tube, weakest where the enhanced lines reach their maximum and increasing gradually to a strength at the top of the tube less than that at the bottom, a difference to be accounted for by the difference in the amount of burning of the tube below and above. (See Curve IV.)

By charging the tube with mixtures of various substances having important lines in the region under observation, it was a simple matter to unify the effects. Thus in the red, the spectra of hydrogen, carbon, titanium, iron, and calcium were obtained on the same plate. In the blue and violet, iron, titanium, and magnesium were frequently combined. The carbon spectrum was always given by the graphite tube. The addition of vanadium and chromium gave the behavior of these elements relatively to the others, while manganese, aluminum, calcium, strontium, barium, silicon, and lead lines appeared from impurities.

The intensity changes in lines from bottom to top of the tube, shown in the curves of Fig. 2, are estimated from typical lines on a number of good plates. The deviations from these intensity gradations were in degree rather than in kind. No approach to an inversion of the effect, such as the maximum of the carbon lines being above the center, or the titanium arc lines failing to weaken in the central portion, was ever observed. As has been noted, λ 4481 of magnesium extended with varying degrees of strength toward the top and bottom of the tube in different photographs. A combination of Curves I and II, with greater strength at the top of the tube than is given by either of them, would probably best represent its average behavior. On two or three plates, the enhanced lines of titanium inclined toward the appearance of the arc lines of that element, but remained relatively strong in the center of the tube, as compared with the arc lines. Deviations of this sort occurred in such a small percentage of the photographs that it was difficult to draw conclusions as to what conditions may have entered to produce them. It has been considered best to use only unreversed lines in judging the intensity variations in the

tube-arc. The region of strong emission is evidently greatly localized at the point where the tube burns through, but the condition of the absorbing vapors in the line of sight is uncertain, these being partly the cooler vapors from the arc and partly furnace vapors in the parts of the tube farther from the arcing portion. The conditions of emission and absorption may be quite different at a given point in the cross-section. However, lines of moderate strength which show no tendency to reverse in any part of their length may be taken as registering the conditions of emission at the part of the tube where the arc is passing.

While the curves of Fig. 2 illustrate the main differences for the lines of the elements studied, it is to be expected that minor differences will appear between elements which have been placed in the same class; and this is the case. By combining the spectra of several elements on the same plate, these small divergences given by the same experimental conditions may be detected and a sequence formed in which the substances are arranged in order according to their sensibility to conditions most favorable to lines strongly characteristic of the spark.

Such a sequence is given below, the elements which show the same behavior for their arc or spark lines, as the case may be, being grouped under the same number, with the numbers increasing according to the divergence from the most pronounced type of spark line.

1. Hydrogen lines (α, β, γ series)
   Spark lines of carbon
2. λ 4481 of magnesium
   Spark lines of lead
3. Enhanced lines of titanium, vanadium, iron, chromium, manganese
4. H and K lines of calcium
5. Arc lines of iron, chromium, manganese, magnesium, aluminum, silicon, tin
6. Arc lines of calcium, strontium, and barium
7. Arc lines of titanium and vanadium

These seven groups are approximately represented by the curves of Fig. 2 as follows:

Curve	I.	Groups	1, 2
"	II.	"	3
"	III.	"	4, 5, 6
"	IV.	"	7

The enhanced lines embraced in Groups 1, 2, and 3 have been described. The lines of Groups 4, 5, and 6 all have their maximum strength above the center of the tube, being relatively weak in the portion which gives the strongest spark lines. The lines H and K of calcium have their maximum strength nearer the center of the tube than do the arc lines of iron and similar elements, though the structure of H and K is rendered somewhat uncertain by their reversals. The reversal becomes narrower toward the center but the line is so much blacker in the negative at this portion that it seems fair to ascribe greater strength to the emission line.

Little difference is to be noted between iron, chromium, manganese, magnesium, aluminum, and silicon as to the structure of their arc lines, but the lines of all these substances retain their strength farther toward the center of the tube than do the arc lines of calcium, strontium, and barium. This was very distinct in photographs of the red region, where a number of strong lines of the latter elements were obtained on the same plates with iron arc lines. The difference between calcium and iron is shown by several lines on Plate XII, *a*. The carbon bands with heads at $\lambda\lambda$ 3884, 4216, and 4382 are strongest near the wall of the tube above and below. They retain their strength toward the center of the tube more in the upper half than in the lower.

All of the lines in Groups 1 to 6 inclusive show their greatest strength in some part of the tube away from the arcing wall. The region near the wall is not to be considered as really destructive to such lines, since every line, if made strong enough, is visible across the diameter of the tube; but certain parts of the cross-section are more favorable than others for a certain kind of line and the differentiation into groups is based on this characteristic.

In contrast to the foregoing groups, we have the arc lines of titanium and vanadium strongest near the wall of the tube, fading toward the part near the center where the enhanced lines of these and other elements are strongest.

Further, I have assured myself that the conditions which favor the various groups of lines exist, in the main, simultaneously. On several occasions, while an exposure with the large spectrograph was being made, the spectrum was observed visually through

the opposite window of the vacuum chamber by projecting an image of the tube's interior upon the (vertical) slit of a prism spectroscope. The appearance at any given moment was the same as that reproduced in Plates XI and XII, the varying strength of the lines in different parts of the tube being very striking. The carbon line λ 4267 (and presumably all of the weaker ones also) developed the greatest intensity shortly before the arc broke, at the time when all features of the tube-arc radiation should have their maximum effect.

DISSYMMETRY OF SPECTRUM LINES IN THE TUBE-ARC

In the previous paper, attention was called to the fact that the wider lines of titanium and λ 4267 of carbon become unsymmetrical in structure in the portion of the tube which gives the enhanced-line radiation most strongly. The later experiments have shown this phenomenon regularly, and have supplied data for the lines of several additional elements. The study of this feature of the tube-arc spectrum is still in a preliminary stage, as the effects have merely appeared incidentally on the plates taken primarily for the study of the intensity distribution in lines of various groups, but the material on hand is sufficient to show the general character of the effect and also the nature of the variations which occur.

If we have a line in the tube-arc spectrum showing partial or complete self-reversal, in most cases the red side of the line is the stronger. The effect is most decided in the part of the tube where the enhanced lines are strongest, and decreases toward the wall of the tube, the line often becoming quite symmetrical close to the wall. It was shown (see the third plate of the former paper) that this takes place only when the tube-arc forms, the same lines being quite symmetrical when given by the regular furnace with unbroken tube. This dissymmetry indicates that the emission line given by the tube-arc is slightly to the red of the absorption line due to the cooler vapors in the line of sight.

On the plates taken in the present investigation, fine examples of unsymmetrical reversal with the red side stronger are given by the more prominent iron arc lines in the blue and violet, notably $\lambda\lambda$ 3886.434, 4250.945, 4271.934, 4308.081, 4325.939, 4383.720,

4404.927, by the aluminum lines λλ 3944.160 and 3961.674, and by the strong titanium arc lines from λ 4513 to λ 4556 which were discussed in the former paper. The strong vanadium lines λ 4091 to λ 4135 are similar. This dissymmetry is always most pronounced near the center of the tube's cross-section, and the same lines appeared nearly or quite symmetrical in the spectrum of the ordinary arc photographed beside that of the tube-arc. A lesser degree of dissymmetry is shown by the titanium arc lines λλ 4298.828, 4300.732, and 4301.158. On plates for which the tube-arc conditions were apparently weaker than usual, these lines were almost symmetrical, while those above λ 4500 retained a certain amount of one-sidedness. λ 4352.083 of magnesium widens strongly toward the red, without reversal.

The H and K lines of calcium show almost symmetrical structure. The red side becomes slightly stronger near the middle of the tube, showing that, like the other lines, such dissymmetry as exists is most decided in that portion of the tube which gives the enhanced lines most strongly. This is in harmony with the observation by St. John[1] of the approximate constancy of the wave-lengths of H and K of calcium in various laboratory sources. The manganese lines λλ 4031, 4033, 4035 show no perceptible deviation from symmetry.

To sum up the situation in regard to dissymmetry, the evidence seems to leave no question that the intense excitation of the tube-arc gives a very decided effect of this sort, but no rule connecting the effect for different lines is as yet apparent. Most of the arc lines so far examined have their red side stronger but some show little or no effect. The hydrogen lines, carbon spark lines, and metallic enhanced lines, when not clearly double, appear very nearly symmetrical in the tube-arc. As was pointed out in the former paper, the condensed spark gives also a one-sided line, usually with the red side strongest. Perhaps it will be shown in general, as was observed by Kent[2] for three zinc lines, that this effect is due to satellites which are enhanced by the spark dis-

[1] *Contributions from the Mount Wilson Solar Observatory*, No. 44; *Astrophysical Journal*, **31**, 143, 1910.

[2] *Proceedings American Academy of Sciences*, **48**, 91, 1912.

charge, thus changing the apparent position of the whole line when viewed with moderate dispersion. If this turns out to be the case, the varying effects of the tube-arc for different lines could result from satellites being enhanced on one side of the main line.

The tube-arc would scarcely be chosen to obtain lines for wave-length measurements, except in the case of those lines which can be produced by it better than by any other source, so that this tendency toward dissymmetry does not present a serious danger in measurements of laboratory spectra. In stellar atmospheres, however, conditions may often be present which closely approach those of the tube-arc, and a study from this point of view may explain many apparent anomalies in the positions of spectrum lines. A criterion as to when displacements of lines from this cause are to be expected would seem to be the prevalence of enhanced lines in the stellar spectrum in question.

THE STRUCTURE OF λ 4481 OF MAGNESIUM

An important feature of the spark line λ 4481 is brought out by the tube-arc photographs. The line appeared always *double*, the violet component being about twice as strong as the red. On most of the plates, the components were separated throughout their length. Other plates gave this line so strongly that the components blended photographically in the strongest part, while they were distinctly resolved at the ends. At first I considered the line as reversed and as an exception to the rule that tube-arc lines usually reverse with their strongest side toward the red. To decide this point the line was photographed on eleven plates, with the scale of 0.89 Å per mm, the intensities varying from the condition where the red component was barely visible up to a state much stronger than that shown in Plate XII, *a*. It was then clear that as long as the components were not so strong as to be blended, the interval between them was very nearly constant. This interval was measured by Miss Sheldon and the writer, a series of twenty determinations being obtained from the eleven plates, the interval being measured in some cases at the middle and at each end of the double line. The measurements, which covered large differences in intensity of the line, ranged from 0.20 Å to 0.23 Å, the majority

being close to 0.21 Å. This approximate constancy of the interval for such intensity variations, together with the fact that the components have the appearance of separate lines, rather than the well-known shaded and unsymmetrical appearance of the sides of a reversed line, offers strong evidence that λ 4481 is really a pair of enhanced lines, which appear to be affected in the same way by tube-arc conditions and presumably by those of the spark. A source in vacuum, either an arc or self-induction spark, combined with a large scale of spectrum, seems to be needed to give a good resolution of the components. The spark in air, even with much self-induction, does not give clear components. When weakened by this means so that the line is barely visible on the plate, it has the appearance of not being a simple line, the maximum being wide enough to contain the two components which the tube-arc shows. The wide line given by the condensed spark is well known to show dissymmetry toward the violet. The measured wave-lengths for this line in sources where it was made moderately narrow have shown much disagreement. Crew[1] and Hartmann,[2] among others, obtained large discordances in wave-length values when λ 4481 was measured on various plates given by the spark and rotating arc. The double structure shown by the tube-arc, combined with the greater strength of the violet component, would make its wave-length when unresolved depend largely on its intensity in the photograph in question, provided the component lines behave alike under varying physical conditions, which seems to be the case. The position of the apparent maximum will at first be that of the violet component when this alone is visible. When both are of moderate strength, the maximum will be between and near the violet component, moving gradually toward the red component as the violet member becomes overexposed.

The two components of λ 4481 have been measured on four plates with reference to $\lambda\lambda$ 4466.727 and 4494.738 (Rowland) of iron, the final values and their probable errors being as follows:

Violet component	4481.284±0.0010
Red "	4481.499±0.0012

[1] *Astrophysical Journal*, 16, 246, 1902.

[2] *Physikalische Zeitschrift*, 4, 427, 1903.

The carbon spark line λ 4267 also is shown by the tube-arc to be a doublet, the separation of the components measuring close to 0.26 Å with the red member rather more than twice as strong as the violet. This line was suspected by Hartmann[1] of being double, but I find no record of the components being resolved. The structure of the doublet has given rise to very discordant measurements of the wave-length by different observers. The wave-lengths of this and of other carbon lines given by the tube-arc will be published when large-scale photographs of the ultra-violet are obtained.

The lower portion of Plate XII presents enlargements of parts of several lines to illustrate their structure, including the magnesium and carbon doublets just discussed and a number of arc lines of which some remain symmetrical and others reverse with the red side strongest. The arc lines of calcium, manganese, iron, aluminum, and vanadium have in each case a portion enlarged from near the middle of their length, where the line is still strong, but is affected by the condition of strong enhanced-line radiation.

INVESTIGATION OF THE PROBABLE CAUSE OF THE TUBE-ARC PHENOMENA

The material thus far presented in this paper has been, like the first paper, simply a record of the experimental results. The classification of spectra which has been made is thus independent of any hypothesis as to the nature of the radiation processes involved. A full explanation of these processes would go far toward solving all questions as to the relation of arc and spark spectra. Some further data will now be presented which serve at least to narrow down the agencies which could bring about these effects.

The fact that enhanced lines in general are stronger in the tube-arc than in the ordinary arc in air is probably due largely to the reduced pressure. Few investigations have been made on the spectrum of the arc *in vacuo*, but such as have been carried out have shown that enhanced lines are strong in this source. Thus Fowler and Payn[2] found that λ 4481 appeared with great intensity in the carbon arc containing magnesium when inclosed in an exhausted

[1] *Astrophysical Journal*, 18, 65, 1903.

[2] *Proceedings of the Royal Society*, 72, 253, 1903.

vessel, though absent at atmospheric pressure; also that the enhanced lines of zinc and cadmium were prominent and the hydrogen line H_β sometimes appeared, probably from gas occluded by the electrodes. Barnes[1] also observed that λ 4481 is strong in a vacuum arc. Gale and Adams[2] found that the titanium enhanced lines are strengthened at reduced pressure. So far as the mere production of enhanced lines is concerned, the present observations on the tube-arc spectrum are to be regarded as additional data on the vacuum arc.

The unique feature of the tube-arc phenomena is the different behavior of the lines of different elements and of the arc and spark lines of the same element, as regards their intensity distribution over the cross-section of the tube. A question of the first importance is the relative temperatures of the vapor at the center of the tube and that near the wall. If the temperature is lower in the center, as would seem to follow if the arc follows the direct path between the ends of the broken tube, then the greater intensity of the enhanced and some of the arc lines away from the wall must be accounted for on other grounds. I have tried to picture a condition in which the temperature at the center might be higher. To be sure it is inclosed by a ring of arc, but experience teaches that the highest thermal condition in an arc is in the center of the path of the current, so that we must have the central vapor conducting as well or better than the graphite walls if the greatest current density is to be at the center. If this were true, we should be looking along the core of a powerful vacuum arc in these experiments. Such a conductivity for the central vapor would appear highly improbable and could conceivably result only from the great concentration of energy at the point of break, giving a very violent vaporization of carbon, which the experiments of Richardson and others have shown to give a high state of ionization.

I have carried out experiments to test this possibility. First an experiment of Harker and Kaye[3] was repeated. Two graphite

[1] *Astrophysical Journal*, **34**, 159, 1911.

[2] *Contributions from the Mount Wilson Solar Observatory*, No. 58; *Astrophysical Journal*, **35**, 10, 1912.

[3] *Proceedings of the Royal Society*, **86** A, 379, 1912.

rods, each of 6 mm diameter, were inserted at opposite ends of the furnace tube, which had an inside diameter of 12.5 mm. The rods, which were supported so as to be coaxial with the tube, were insulated from each other and from all parts of the furnace. The inner end of one rod was placed midway in the tube's length, so as to be in the hottest portion, the end of the other rod being near the end of the tube, in a relatively cool position, about 7.5 cm from the end of the first rod. Wires passed from each rod through an insulating plug in the head of the furnace chamber and to a direct-current ammeter. The tube was heated as usual by alternating current. When the chamber was pumped out and the tube heated to about 2600° C. at its central portion, the ammeter showed a direct current of about 1.5 ampere, varying only slightly on repeated trials. The cooler electrode was the positive one.[1] Although the phenomenon is somewhat complex, as Harker and Kaye have pointed out, it clearly gives us a current of considerable magnitude caused by the passage of negative corpuscles from the hot electrode to the cooler one. During one experiment, the tube burned apart at its middle, forming the tube-arc around the end of the inner electrode rod. The intense heating of the latter caused the ionization current to reach a value of 2 amperes.

The presence of a vigorous ionization being established, the next step was to measure the resistance of a column of heated vapor in the tube between the ends of two exploring electrodes and compare this with the resistance of the graphite tube itself. Two graphite rods similar to those used in the experiment just described were supported coaxially in the tube with their inner ends near the middle of the thin portion of the tube which was turned down for a length of 5 cm as in the tube-arc experiments. The ends of these exploring rods were 12 mm apart. The wires

[1] While the matter has no direct bearing on the present research, it may be noted here that a series of measurements was made at varying pressures, up to 20 atmospheres, keeping the apparatus as nearly as possible in the condition just described. A rapid decrease of ionization current with increasing pressure was observed up to 4 atmospheres (with compressed air) when 0.008 ampere was recorded. The fall in current values then became slower, and finally at 20 atmospheres, a current of 0.0015 ampere remained. While not enough check measures were taken to justify placing high weight on the values obtained, the general character of the change was brought out clearly, and it was evident also that even at high pressures the ionization is appreciable.

connected to them passed out of the furnace as before and were joined to a 6-volt battery with ammeter and a fixed resistance in series. The voltage across the electrode rods was read on a millivoltmeter which recorded a known fraction of the total voltage by means of a subdivided resistance. It was thus possible to take simultaneous readings of current and voltage at any stage after the vapor in the furnace tube had become conducting. Pyrometer readings of the tube temperature were made at the same time.

As soon as the tube became incandescent, a current appeared in the ammeter circuit, with corresponding reduction of the voltage across the electrodes. When the tube was heated to a state similar to that usually existing just before the formation of the tube-arc, the lowest resistance of the vapor between the electrodes, calculated from the current and voltage readings, was 1.1 ohm. This was with no metallic vapor in the tube except from impurities in the graphite. When a little titanium was put in the tube, the apparatus was in the same state as in many of the tube-arc experiments. The lowest resistance recorded with titanium vapor present was almost exactly 1 ohm. At the same time the resistance of the heating circuit of the furnace, which included the whole of the graphite tube and several contacts, was approximately 0.02 ohm. The current measured in the exploring circuit probably for the most part did not pass through the 12 mm of vapor between the ends of the electrodes, but leaked from each electrode to the wall of the tube about 3 mm distant. Even with such favorable conditions for the passage of a large current when the vapor in the tube becomes conducting, the resistance of this vapor is found to be large compared to that of the graphite wall.

The application of these results to the question as to whether the central vapors of the tube-arc can be regarded as the core of the arc, and thus as the region of the highest temperature, is that when the tube-arc forms, nearly all of the current must follow the shortest path between the ends, instead of curving through the central portion of the tube, about 6 mm distant. The view advanced in the former paper thus appears to be justified, that the enhanced lines are strong near the center of the tube in spite of the fact that the main path of the current is at the wall.

The arc lines of iron were expected to afford evidence as to the resemblance of different portions of the tube-arc to the core and flame of the ordinary arc, and, perhaps, by applying the data for intensity variations at different temperatures obtained by the writer[1] with the electric furnace, to indicate the nature of the temperature differences. It is well known that certain lines of iron are given chiefly by the outer vapors of the arc, others almost wholly by the core, while intermediate classes occur in both regions, being given most strongly by the intense radiation of the core. If corresponding variations exist in the tube-arc, a difference should appear in the position of the maximum strength of arc lines given by the long slit used in these experiments. The photographs show a very definite condition, though one scarcely to be expected. The "flame" lines of iron, strong in the outer vapors of the ordinary arc and relatively strong at the lower temperatures of the electric furnace (classes I A and I B of the furnace classification) are relatively weak in the tube-arc. Evidently no part of the cross-section gives a spectrum similar to that of the arc-flame, but neither is there evidence of strong core conditions. The relative intensities of a number of iron lines in the green-yellow afford a good test-spectrum for this purpose, a part of these lines being given almost entirely by the core. Such lines are only moderately strong in the tube-arc. The tube-arc spectrum, in fact, most closely resembles that given near the poles of the ordinary arc, on account of the relative strength of enhanced lines. A surprising feature is that no distinct difference is to be detected between the position of the maximum of a flame line which is barely visible in the tube-arc and that of a strong core line. At any rate, the difference is not as great as that between arc lines of iron and calcium, which results in the differentiation given on p. 323. The enhanced lines of iron, on the other hand, of which all of the stronger ones in the blue and green come out clearly in the tube-arc, show a distinctly different form, closely resembling the enhanced lines of titanium.

The only conclusion to be drawn from this test is that the radiation in all parts of the tube-arc is of a very intense character and

[1] *Contributions from the Mount Wilson Solar Observatory*, No. 66; *Astrophysical Journal*, 37, 239, 1913.

that differences in the arc lines which should result from a large temperature variation between center and wall do not appear.

The later experiments, with the slit along the vertical diameter of the image, do not point to differences in vapor density exerting a large influence. The supply of metallic vapor was always from below, whether the material was placed in the tube or in the jacket beneath. The region giving the strongest enhanced lines, while not in the lowest portion of the tube, is below the center, where a moderately high vapor density should prevail. If there is any large departure from uniformity in the vapor distribution, the region of least density should be above the center, and in this portion we find the arc lines at their strongest. As light sources in general do not show that a high vapor density is especially favorable to enhanced lines or that a rare condition is best for arc lines, it would seem probable that the vapor distribution is not a controlling agent in the tube-arc effects.

We may next consider the effect of a combination of thermo-luminescence and electro-luminescence, both of which must be active in this source, and whether the effects observed can be accounted for by a predominance of one or the other kind of radiation in a given portion of the tube. The distinction which modern theory makes between thermo- and electro-luminescence may be given briefly. In thermo-luminescence, the radiating vapor is highly heated, and the electron which imparts the light vibration to the ether derives its energy from the translatory motion and collisions of the heated molecules. Electro-luminescence, as exemplified in the discharge through vacuum tubes, does not require a heated state of the gas, but the energy of the light vibration is considered to arise from the impact of free corpuscles striking the vapor particles. To have a strong state of electro-luminescence in the tube-arc would thus require a plentiful supply of high-speed electrons bombarding the vapor. There can be no doubt that electrons in enormous quantities are shot off from the ring of intensely heated graphite where the arc forms. Their speed is probably much less than is attained with spark potentials, but they have as much velocity as a temperature generated by many kilowatts in the arc can give them, aided by the partial vacuum. The intense brilliancy of the hydrogen lines in the tube-arc

bears out the idea of a strong electro-luminescence, since that is the excitation which prevails in vacuum tubes, the source usually employed in the study of this spectrum. As regards the enhanced lines of metals, there seems to be no clear exception to the rule that a large potential gradient is needed for their appearance in the arc and spark. Thus in the continuous arc, if enhanced lines appear at all, they are close to the poles, where the potential fall is the most rapid. The interrupted and rotating arcs obviously give a strong potential gradient in the constantly recurring breaks, and the production of enhanced lines in such arcs has been ascribed to this feature. In the spark discharge, disruptiveness is recognized as an essential condition for strong enhanced lines. The analyses of the spark carried out by Hemsalech[1] and later by Schenck,[2] in which the separate oscillations were photographed by means of a rotating mirror, showed that the enhanced lines are due mainly to "streamers" projecting from the poles at the beginning of each spark. The electric field acting in these streamers should be much greater than that in the later oscillations which pass across the spark gap. The well-known effect of self-induction in weakening the enhanced lines was shown to be due to a damping of these initial oscillations, the chief energy of the discharge going into the later pulsations which the rotating mirror and spectrograph showed to radiate mainly arc lines.

The natural conclusion, which has been repeatedly expressed in substance by investigators of the arc and spark phenomena, is that large potential gradients in the arc and disruptiveness in the spark reduce in each case to a condition of high electronic speed, and that the lines peculiar to the spark are those which require this electro-luminescence, given by the impact of high speed corpuscles on the vapor particles. If this is recognized as the essential condition for the production of enhanced lines, it opens the way to account for their presence in sources where a high potential does not exist, and whose resemblance to the spark might seem, therefore, to be very slight. Thus it seems reasonable to the writer that a moderately strong state of electro-luminescence

[1] *Recherches expérimentales sur les spectres d'étincelles*, Dissertation, Paris, 1901.

[2] *Astrophysical Journal*, 14, 116, 1901.

should be present in the tube-arc, resulting from the ejection of large quantities of electrons from the highly heated carbon, and that the strength of the enhanced lines, which in general is intermediate between that shown by the ordinary arc (near the poles) and by the condensed spark is to be accounted for in this way.

It remains then to account for the greater strength of the enhanced lines in the central part of the tube's cross-section, away from the wall which is the source of the supply of electrons. It is to be remembered that this is a relative condition, that the enhanced lines are given near the wall as well, so that the greater strength near the center would result through an increase in the number of electronic impacts which are occurring in some degree in all parts of the tube.

It may be that we need not look farther than the form of the tube for the cause of this strengthening. Electrons shot out normally to the heated surface should have the highest velocities, and the number of collisions with the vapor particles will obviously be greatest near the center of the tube. If the tube were placed vertically (an arrangement unfortunately not permitted by the present apparatus), a uniform burning of the arc around the circumference should take place, resulting in the location most favorable for enhanced lines being at the center. The more violent burning at the bottom of the tube, extending over about one-third of the circumference, would give a much greater supply of electrons emanating from this region, probably having somewhat higher velocities than those given by the weaker arc at the top, and the curvature of the wall would result in a greater number of impacts in unit time in the region below the center. The intensity distribution of the most typical spark lines, such as those of carbon and hydrogen, would then be explained. Enhanced lines such as those of titanium and iron, which appear in the ordinary arc, show only a slight diminution toward the bottom of the tube.

The radiation conditions in the region above the center of the tube are to be studied next, since an important class of arc lines is found to be strongest there. It would seem that the concentration (by virtue of the curvature of the wall) of the less numerous and probably slower electrons from the upper part of

the tube would give a radiation less intense than that below the center, but still having more of the qualities of electro-luminescence than the vapor close to the wall. The behavior of the enhanced lines is in harmony with this view, and it would mean that the arc lines of iron and several other elements respond more strongly to a moderate electro-luminescence than to the strong thermo-luminescence which probably prevails at the wall.

We could leave the phenomena of the tube-arc here, as being in the main accounted for by the concentration toward the center of the tube of the electronic bombardment, were it not that the arc lines of titanium and vanadium show a decided preference for the region near the wall. The distinguishing conditions at the wall are high temperature due to the proximity of the incandescent carbon, and probably fewer impacts by electrons than occur toward the center. If the first of these conditions governs the radiation of the titanium and vanadium arc lines, we have an interesting agreement with a peculiarity of electric furnace spectra, viz., that for titanium and vanadium the furnace at moderate temperature gives much more nearly a complete arc spectrum than it does for iron. The difficulty in producing a great many iron lines in the furnace which are strong in the arc was discussed in a paper[1] on this spectrum. With titanium and vanadium, the case is very different, in spite of the high melting point of these substances. Almost all lines shown by the arc, excepting enhanced lines, are given by the furnace at about 2400° C. Since the radiation of the furnace is probably as nearly thermal as any we have, while that of the arc is undoubtedly largely electrical, this is evidence that the vapors of titanium and vanadium respond to a condition of thermo-luminescence better than does the vapor of iron. In the tube-arc, granting a relatively strong state of thermo-luminescence near the wall, the observed behavior of the titanium and vanadium arc lines would be expected.

Referring to the curves of Fig. 2, the hypothesis just presented would make Curves I and II correspond to a state of high and Curve III to moderate electro-luminescence, while for Curve IV

[1] *Contributions from the Mount Wilson Solar Observatory*, No. 66; *Astrophysical Journal*, **37**, 239, 1913.

thermo-luminescence predominates. The spark gives the strongest electro-luminescence and would be chosen to produce the enhanced lines of Curves I and II. The moderate electro-luminescence of the arc makes it the most efficient source for the lines of Curve III; while the thermo-luminescence of the furnace is sufficient to give almost complete spectra for the elements corresponding to Curve IV.

It is mainly because the recognized characteristics of spark, arc, and furnace spectra fit in so well with this hypothesis as to the varying strengths of electro- and thermo-luminescence in different parts of the tube-arc that I have felt justified in offering it. If the results obtained with the tube-arc are considered from this point of view, I find in them nothing that is anomalous or necessarily in contradiction with any recognized spectroscopic phenomena. Direct evidence as to the electrical state of the vapor is difficult to obtain, since the introduction of anything in the nature of an exploring electrode would modify by an unknown amount the regular conditions. I have, however, tried to alter the form of the tube to approach two parallel plates by cutting away opposite sides of the tube. When much of the material was thus removed, the arc would not hold, the inclosure of a large amount of carbon vapor before the formation of the arc seeming to be required. By reducing the size of the openings until holes about 3 mm in diameter above and below at the middle of the tube were left, I was able to get the tube-arc to act. The concentration of electronic impacts should have been somewhat reduced in this way. The H_α line was observed in particular, with hydrogen present at reduced pressure. The line, while still strongest at its middle, showed a nearer approach to uniformity throughout its length than when the regular tube without openings was employed. While this was the expected result, the experiment was not altogether conclusive, since the temperature and vapor distribution in the tube were altered by the openings.

Aside from the question as to why the enhanced lines are stronger near the center of the tube, their mere appearance in the vapor of a low-voltage arc is evidence either of a kind of excitation in this source similar to that which is regarded as an electro-

luminescence in the arc and spark, or of a temperature so high as to produce a light-energy usually imparted only by the impact of high-speed electrons.

The current in the tube-arc is very large, but the employment of high currents in an ordinary arc has never proved effective in producing enhanced lines. Hartmann[1] showed that very small currents are more favorable. Also, the evidence seems to be against a temperature increase in the part of the tube-arc which gives the enhanced lines most strongly. If the radiation be considered as probably due largely to the impact of electrons, evidently the temperature of the carbon which emits these electrons exerts a controlling influence. The phenomenon thus has a thermal basis, but the important difference from thermo-luminescence is that the vapor which emits the light need not itself be in a region of high temperature.

The amount of carbon present in a source emitting electrons is evidently highly important on account of the rich discharge of corpuscles from this substance. Thus, if two bodies are at the same temperature, but one of them contains more carbon than the other, the vapor in the vicinity of the one richer in carbon should give enhanced lines most strongly. It is doubtful, however, if a high percentage of carbon can compensate in any large degree for a deficiency in temperature; since it is the energy of the impacts, rather than their number, which determines the main features of the effect.

It is beyond the scope of this paper to take up the numerous applications which may be made in the field of astrophysics, the object of the work being to present in some detail the leading features of the spectrum of the tube-arc, and by a comparison with other sources to infer the probable character of its radiation.

SUMMARY OF RESULTS

The features of this investigation not covered in the former paper may be summarized as follows:

1. In the study of the tube-arc spectrum, a region near the center of the tube's cross-section has been found to give the

[1] *Astrophysical Journal*, 17, 270, 1903.

hydrogen spectrum and the enhanced lines of metals most strongly, with some variation among different elements as to how rapidly their enhanced lines diminish in intensity toward the wall.

2. The arc lines of two groups of elements, represented by iron and calcium, show different degrees of response to the conditions most favorable for enhanced lines.

3. The arc lines of titanium and vanadium differ from those of the other elements studied, showing their greatest strength close to the wall.

4. Additional data have been obtained on the dissymmetry of lines produced in the central portion of the tube. While this is usually toward the red, some lines show little or no effect. The dissymmetry of λ 4481 of magnesium and of λ 4267 of carbon is explained by the observation that these lines are apparently double.

5. Tests have been carried out on the ionization of the vapor and on its conductivity compared to that of the tube material. The results of these, together with the spectroscopic phenomena of the tube-arc, indicate that the effects may be largely due to the impact of electrons emitted by the highly heated carbon, the resultant effect of these impacts becoming stronger near the center of the tube.

MOUNT WILSON SOLAR OBSERVATORY
May 1913

RADIAL MOTION IN SUN-SPOTS[1]

II. THE DISTRIBUTION OF THE ELEMENTS IN THE SOLAR ATMOSPHERE

By CHARLES E. ST. JOHN

In the previous paper on "Radial Motion in Sun-Spots"[2] the displacements at the peripheral edges of the spot penumbrae were given for some five hundred solar lines. The spots at the times of observation were between 25° and 60° from the center of the disk, and the slit of the spectograph was parallel to the radius of the solar image passing through the center of the spot umbra. The displacements were found to vary as the wave-length, and are interpreted as due to the Doppler effect arising from movements of the vapors of the reversing layer and chromosphere, tangential to the solar surface and radial to the axis of the spot vortex. The observations are in harmony with the explanation suggested by Evershed when he reported the existence of such displacements.[3] For convenience of reference in the course of the discussion, and to connect them with sun-spots by indicating their relation to the flow radial to the axis of the spot vortex, these displacements will be referred to as "radial displacements." For the purposes of discussion and comparison they have been reduced to the limb and to a common wave-length λ 5000, on the assumption that they are produced by movements of the solar vapors parallel to the solar surface. Displacements that indicate an outflow are called positive and displacements indicating inflow, negative. An increase of the displacements indicating outward flow with the decrease in the intensity of the lines of the reversing layer and the increase of the displacements indicating an inflow with the increase in the intensity of the chromospheric lines are striking aspects of the phenomena. The assumption is made that, on the whole, the lines of decreasing intensities are produced at increasing depths, and

[1] *Contributions from the Mount Wilson Solar Observatory*, No. 74.

[2] *Contributions from the Mount Wilson Solar Observatory*, No. 69; *Astrophysical Journal*, **37**, 322, 1913.

[3] *Kodaikanal Observatory Bulletin*, No. 15, 1909.

therefore the direction and the speed of the flow may be considered a function of the depth. The displacements vary from large positive values for the lines of very low solar intensity to large negative values for the strongest calcium and hydrogen lines, and pass through zero values in the case of the strongest lines of aluminum and iron. The series of displacements for the iron lines of intensities 00 to 10, when arranged in the order of increasing intensities

TABLE I

IRON SCALE. DISPLACEMENTS REDUCED TO λ 5000 AND EXPRESSED IN ÅNGSTRÖMS

Intensity	00	0	1	2	3	4	5	6	7	8	10
Displacements	0.034	0.030	0.028	0.025	0.023	0.021	0.019	0.016	0.012	0.009	0.004
Vel. km/sec	2.04	1.80	1.68	1.50	1.38	1.26	1.14	0.96	0.72	0.54	0.24

Mean interval per unit intensity = 0.0026 Å = 0.16 km/sec.

TABLE II

DISPLACEMENTS IN ÅNGSTRÖMS OF STRONG LINES (λ 5000)

	ELEMENT						
	Mg	*Si*	*Al*	*Fe*	*Sr*	*Ca* λ 4227	H_δ
Intensity	10	12	15–20	15–40	20	40	40
Displacements	+0.002	0.000	0.000	0.000	−0.002	−0.002	−0.005
Vel. km/sec	+0.12	0.00	0.00	0.00	−0.12	−0.12	−0.30

	ELEMENT					
	Na D_1, D_2	*Mg* b_2, b_1	H_γ	*Ca* H_2, K_2	H_α	*Ca* H_3, K_3
Intensity	20, 30	20, 30	20		40	
Displacements	−0.012	−0.012	−0.033	−0.044	−0.050	−0.063
Vel. km/sec	−0.72	−0.72	−1.98	−2.64	−3.00	−3.78

of the lines, shows the march of the phenomena and also forms a scale with which to compare the displacements of lines of other elements of like intensities. It is deduced from the displacements of some 200 iron lines of intensities 00 to 10—all that were observed between these intensities—and represents a general mean into which the influence of the different groups of iron lines and of the different spectral regions enter in varying proportion.

Displacements throughout the paper are the relative displacements at the two edges of the penumbra, so that the displacements and the velocities are to be divided by two to obtain the absolute values.

For lines stronger than 10, the displacements are either very small or negative, and, in the latter instance, they increase numerically with the elevation; that is, they are greatest for what are known to be high-level lines.

The lines of Table II are in the main as characteristic of the chromosphere as those of Table I are of the reversing layer. The neutral region, the level of zero velocity, corresponds to the usual line of division between the reversing layer and the chromosphere, and seems to offer another ground for the customary division.

THE CHART OF DISTRIBUTION

When the displacements of the lines of different elements are compared, it appears that the displacements of the lines of like intensity differ. With the iron scale (Table I) established, it is possible to determine the relative levels in terms of this scale at which the lines of other elements are produced. A comparison for the violet region is shown in Table III for the lines of titanium, lanthanum, and cerium, where their displacements are compared with those of iron lines of the same intensity and in the same spectral region.

TABLE III

COMPARATIVE DISPLACEMENTS OF LINES OF EQUAL INTENSITY

Intensity	*Fe*	*Ti–Fe*	*La–Fe*	*Ce–Fe*
1	0.0264	−0.0021	+0.0026	+0.0066
2	.0240	− .0030	+ .0033	....
3	.0186	− .0020	+0.0070	+0.0074
4	.0181	− .0041	....	....
5	0.0166	−0.0041	....	....
Weighted mean	....	−0.0026	+0.0033	+0.0070
Levels referred to iron	....	1 unit above	1.3 units below	2.7 units below

The titanium lines are consistently displaced less than the iron lines, indicating that the former originate at a higher level; and the

lines of lanthanum and cerium are as consistently displaced more than the iron lines; hence the origin of these lines is assigned to a lower level than that of the lines of iron of the same intensity.

The relative levels of the lines of 26 elements have been determined by comparing the displacements of their lines with those of the lines of iron of equal intensity and in the same spectral region. The relative levels of the absorbing regions to which the various lines owe their origin are indicated in the chart (Fig. 1). In the case of iron, the displacements are entered in the diagram for each intensity. In the vertical columns the figures in the small rectangles indicate the intensities of the lines, and the position of the rectangles the corresponding levels; the figures in circles refer to the lines of the element stronger than any measured upon these plates; for lines stronger than 10 the actual displacements are given reduced to λ 5000. The absolute velocity may be found from the displacements by multiplying by 30. The vertical scale is entirely arbitrary. From 000 to 8 the ordinates vary as the intensities; one division of the scale corresponds to one unit of intensity and equals 0.0026 Å. For stronger lines the relative levels indicated are proportional to the actual displacements, and one scale division equals 0.0075 Å.

In speaking of the level at which a given line originates, it is to be borne in mind that this is not sharply bounded, but that some portion of the whole depth of the gas is more effective than all the rest in the production of the line. From the point of view that no light from the continuous spectrum background appears in the Fraunhofer lines and that their relative intensities depend upon the light in the lines emitted by the gases, it is evident that light of the wave-length considered, coming from the lowest depths from which it can reach the surface, emerges greatly reduced by absorption and scattering; that light from the lesser depths is greatly weakened because of lower temperature; and that it is the region between these two extremes that may be considered the effective layer.[1] If it be considered that the Fraunhofer lines are formed by partial absorption and that their intensities depend in large measure upon the light of the corresponding wave-length transmitted

[1] Abbot, *The Sun*, pp. 251–252, 1911.

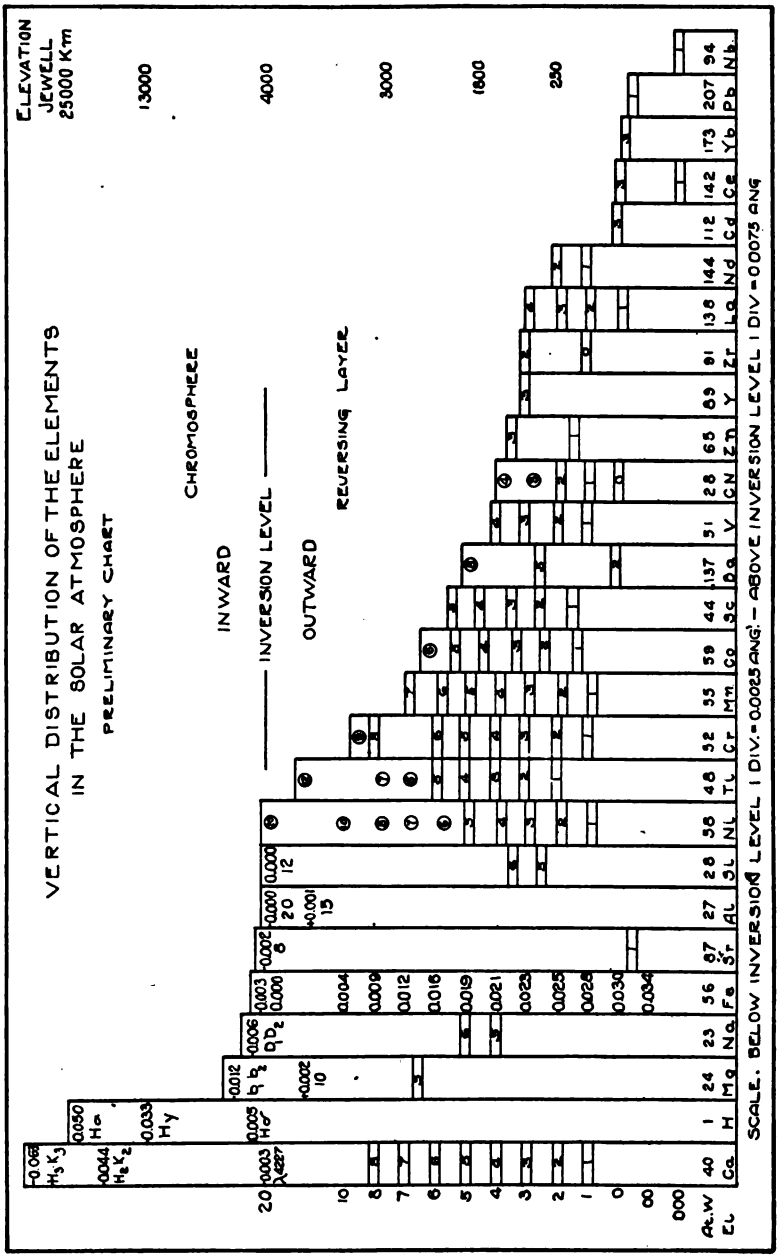

VERTICAL DISTRIBUTION OF THE ELEMENTS
IN THE SOLAR ATMOSPHERE
PRELIMINARY CHART
ELEVATION
JEWELL
25000 Km
13000
4000
3000
1800
250
CHROMOSPHERE
INWARD
INVERSION LEVEL
OUTWARD
REVERSING LAYER
At.W 40 1 24 23 56 87 27 28 58 48 52 55 59 44 137 51 28 65 89 91 138 144 112 142 173 207 94
EL Ca H Mg Na Fe Sr Al Si Ni Ti Cr Mn Co Sc Ba V CN Zn Y Zr La Nd Cd Ce Yb Pb Nb
SCALE. BELOW INVERSION LEVEL 1 DIV.=0.0025 ANG. — ABOVE INVERSION LEVEL 1 DIV = 0.0075 ANG

FIG. I

from the background, it is evident that the lowest regions having nearly the temperature of the photosphere would have small absorptive effect; that the upper limits of the gas are extremely rare and would, for most lines, produce little absorption; and that the main absorption would be due to the intermediate or effective layers, the level of which depends upon the selective absorption in the lines considered.

It will be noticed at once that high atomic weights are more numerous toward the right of the chart, pointing to a low level even for the strongest lines of the heavier elements. This becomes more evident when the atomic weights are taken in groups from left to right. Placing seven elements in the first group, and five in each of the others, we have from left to right:

	Group				
	1	2	3	4	5
Total atomic weight....	258	241	319	527	728
Mean atomic weight....	37	48	64	105	146

The upper limit at which the vapor of any element may be spectroscopically detected depends upon the strength of its lines; the stronger the lines the higher the level at which they can be detected. It might be thought that, if all elements had lines of equal intensities in the solar spectrum, the substances would be detected at equally high levels. But on the chart it will be noticed that the lines of the heavy elements, such as barium, lanthanum, neodymium, cadmium, cerium, lead, and ytterbium, originate at lower levels than the lines of like intensity of iron, and it might well follow that lines of these elements of greater intensity than those measured would also originate below the levels of the iron lines of equal intensity.

There are some interesting exceptions to the general tenor of the chart. The high level of calcium as shown by the H and K lines stands out as strikingly on the chart as in eclipse spectra and remains still an enigma. Cyanogen appears far to the right of iron, and strontium reaches a level higher than several elements of lesser atomic weight. The effect of the presence of metallic vapors

in the arc upon the lines of cyanogen or carbon is well known to be the almost complete extinction of the cyanogen lines, and it appears that the same conditions probably obtain in the gases of the solar atmosphere. The strong line of strontium λ 4077 is remarkably prominent in flash spectra; it is also enormously enhanced in the spark, and enhanced lines are at higher levels than unenhanced lines; that is, they show smaller radial displacements than unenhanced lines of the same solar intensity. It is to be remarked also that the strontium line λ 4161, intensity 1, originates at a much lower level than iron lines of the same intensity—shown by consistent measurements on 13 plates—so that the placing of strontium so far to the left in the chart depends upon the high level reached by what seems an exceptional line, while the level of the weaker line would place it farther to the right where its atomic weight would fall into the general scheme. The elements grouped around strontium in the chart differ but slightly in the levels given by their strongest lines. Their arrangement is therefore very uncertain and liable to change with additional data. The lines of intensities 5 and 6 assigned to silicon, which point to a low level for this element, are of interest in that λ 5948, intensity 6, was identified by Rowland as silicon; but it has never been observed since in the spectrum of this element, and its origin is doubtful.[1] Its relative position depends upon the measurement of 24 plates. The low level assigned points to the possibility of its being a line of one of the rare earth elements present as an impurity in the sample used for the identification by Rowland, or to its being a blend. Nothing is known of the source of the silicon that Rowland used. The line λ 4103, intensity 5, is a blend of silicon and manganese. The components would each be of lesser intensity, and their displacements correspondingly greater than in the case of a single line of intensity 5. In the complete list of lines observed appearing in *Contributions from the Mount Wilson Solar Observatory*, No. 69, there are 8 blends of mean intensity 4. The mean displacement of these lines is 0.024 Å, while the mean for other lines of the same elements and of equal intensity is 0.018 Å, indicating that the blends are at the level of lines of one-half their intensity. The

[1] Kayser, *Handbuch der Spectroscopie*, 6, 482, 1912.

element niobium appears farther to the right than its atomic weight would seem to place it; but from the scarcity of the metal in the earth, one would be justified in believing that it and other rare earth metals form a very small part of the accessible solar atmosphere and are confined to a low level.

Taken by and large the spectroscopically determined levels may be considered to represent the approximate state of things. Much fuller laboratory data are greatly needed upon such points as follows: in the case of iron, nickel, and cobalt, for example, what are the relative intensities of the lines when produced under like conditions of excitation, temperature, and density? What changes occur when present in a mixture? The estimation of the intensities of the lines in the spectra of the elements is a very arbitrary matter. It would be of great service if some workable standard were devised, such, for example, as the iron arc under fixed conditions, and if it were possible to say even approximately how the lines of an element compare in intensity with certain lines of iron under similar conditions of density and temperature. The nearer the comparisons approach a quantitative basis the more valuable they would be. The electric furnace is capable of yielding a large mass of valuable data, as King has shown in the case of calcium and iron.

SPECIAL GROUPS AND REGIONS

In obtaining the mean displacement of the lines of a given intensity of any element, no consideration has been given thus far to the characteristics of individual lines or of the lines belonging to any particular group. In the paper on "Radial Motion in Sun-Spots, I" a comparison was made between lines in the violet and red for lines of equal solar intensity. From this comparison, it appeared that the lines in the red gave displacements about 0.005 Å greater than those of the same intensity in the violet, thus indicating a level for the lines in the red about two intensities lower than for lines of like intensity in the violet.

The original observing program contained a large number of enhanced lines, but they were not indicated as such in the working lists. It was the custom to select the lines that seemed best

adapted to measurement, when they were numerous enough to offer a chance for selection as in the case of iron, titanium, chromium, and nickel. When the data were finally assembled it was found that the enhanced lines had nearly all been eliminated by a kind of natural selection, which tends to show that they are more difficult to measure than other lines of the same elements and is a further indication that they form a distinct class. Blends aside, there are fourteen enhanced lines in the list for which comparisons with other lines of like intensity of the same elements are possible. The displacements of these lines are less than for the corresponding lines of the same elements, and point to a level for the enhanced lines higher than for unenhanced lines of like solar intensity; and there is some ground for thinking that the difference in level increases with the degree of enhancement.

TABLE IV

RELATIVE DISPLACEMENTS OF THE ENHANCED LINES

Elements	Intensities	Enhanced − Unenhanced	No. of Lines
Ti, Fe, Cr, Ni......................	2	−0.0033	9
Ti...............................	3	−0.0046	4
Ti...............................	4	−0.0021	1
Weighted mean.................		−0.0037	

As to the relatively high level indicated by the smaller radial displacements of enhanced lines, this seems explicable from the behavior of enhanced lines in spots. Mr. Adams has given the results for the known enhanced lines—144 lines—in his paper.[1] Of this number, 130 are weakened and none are strengthened in spots. It is also clear from Mr. Adams' summary that the percentage of weakening increases as the lines decrease in intensity, since the absolute change expressed in intensity units is approximately the same for lines of all intensities; lines of solar intensity 0–2, 3–4, and 5–6 are decreased by 1.3, 1.4, and 1.4 units, respectively.

[1] *Contributions from the Mount Wilson Solar Observatory*, No. 40; *Astrophysical Journal*, 30, 86, 1909.

It has generally been considered that high temperature is a condition for the production of enhanced lines. From this point of view, the lessened intensity in spot spectra of enhanced lines produced throughout the reversing layer may be attributed to the lower temperature in spots. The weakening is greatest for low-level lines, which points to decreasing temperature as one approaches the levels in which these lines originate. In the case of any particular line, the lessened temperature of the lower portion of the layer effective in its production would tend to weaken the line and at the same time to raise its effective level by increasing the relative contribution of the upper portion of the layer. The changes of intensity are not confined to the spot umbra, but occur also in the penumbra, only less marked. The radial displacements refer to the peripheral edges of the penumbra, and the high level of the enhanced lines, relative to the level of other lines of the same solar intensity, may be a phenomenon peculiar to spots, and not indicative of a condition generally obtaining in the solar atmosphere.

The behavior of the enhanced lines under various conditions offers a fruitful field for investigation. They undoubtedly occur in flash spectra with greater relative intensity than other lines of a like solar intensity. Gale and Adams called attention to the great increase in relative intensity which the enhanced lines show in photographs of the titanium arc under reduced pressure.[1] This is a very marked phenomenon. Enhanced lines which under normal pressure are one-half the intensity of certain arc lines rise to double the intensity of these same lines when the pressure is lowered to 10 cm. Their suggestion that this change of relative intensity may have an application to the chromosphere is strengthened by the consideration that the Fraunhofer lines originate in rather definite levels. These levels are fixed by the mean depth at which the emergent light of the particular wave-length originates. At the edge of the solar disk the increased depth of the absorbing vapor raises the level from which light of a given wave-length can reach the surface; that is, we see into the sun to a less depth, so that the source of the lines in the flash spectrum is in

[1] *Contributions from the Mount Wilson Solar Observatory*, No. 58; *Astrophysical Journal*, **35**, 45, 1912.

a region of reduced pressure, and the relative intensities of the enhanced lines are increased.

The recent work by King upon the tube-arc spectrum of titanium in the electric furnace has shown that the enhanced lines may be relatively strong under conditions that seem not to depend directly upon temperature or great fall of potential. For a few seconds after the break of a furnace tube thinned in the central portion, the spectra, when the slit extends along the whole diameter of the tube, show the enhanced lines of titanium of nearly equal intensity from wall to wall, while the arc lines are strong near the walls but very weak in the axial portion of the tube. The conditions throughout the cross-section of the tube are equally favorable to the production of the enhanced lines of titanium, but relatively unfavorable for the production of the unenhanced lines in the axial region. The vapor producing these spectra is at the time surrounded by a wall of arc consuming approximately 24 kilowatts, supplied for a period of from 5 to 15 seconds under a potential fall not exceeding 33 volts. To the lower temperature of the axial region may be attributed, in part at least, the lessened intensity of the middle portions of the unenhanced lines. That the vapor density also may be less near the axis of the tube seems to be indicated by the behavior of the enhanced line of carbon, λ 4267—strong in the center and scarcely visible at the wall of the tube—as a high density of the other vapors near the wall would tend to obliterate it and a lessened density near the axis would be favorable to its production. If high temperature and low density are both favorable conditions for the production of enhanced lines, the effect of the fall of temperature toward the axis may be so nearly compensated by the effect of decrease in density that the enhanced lines may retain a nearly uniform intensity from wall to axis. The increased relative intensity of the enhanced lines under decreased pressure observed by Gale and Adams and by Barnes[1] is then a related phenomenon and the behavior of the enhanced lines in flash spectra would follow from the decreased density due to the higher elevation of the effective levels at the sun's limb.

Certain groups of iron lines based upon pressure displacements

[1] *Astrophysical Journal*, **34**, 163, 1911.

have been pointed out by Gale and Adams, namely, groups *b* and *d*.[1] To these have been added by Miss Ware and myself the groups *sub-d* and *e*. From a study of the eclipse results of Frost[2] and Mitchell[3] it appears that the lines of group *d* are at a higher elevation in the solar atmosphere than those of group *b*. The comparison, to be of force, should be between lines of the same intensity. Of 24 lines, mean intensity 5.3, belonging to group *b* present in the region included in the flash spectra, 75 per cent are present in the lists of Frost and Mitchell. Of 8 lines of mean intensity, 4.9, belonging to group *d*, 90 per cent are present, though the advantage of intensity is in favor of lines of group *b*. The spectral regions covered by the present investigation did not include regions where lines of groups *d* and *e* are most common. In Table V are given the residuals obtained by deducting from the displacements of the known lines of these three groups the means for all the iron lines of like solar intensity.

TABLE V

RESIDUALS

Intensity	Group *b* 24 Lines	Group *d* 9 Lines	Group *sub-d* 3 Lines	Group *e* 5 Lines
Fe 1	+0.0022 Å	....	....	−0.012 Å
Fe 3	+0.0025	....	−0.004 Å	....
Fe 4	+0.0003	+0.001 Å	−0.011	+0.004
Fe 5	+0.0039	−0.003	−0.010	−0.004
Fe 6	+0.0050	+0.001	....	....
Fe 7	+0.0003	0.000	....	....
Fe 8	+0.0010	−0.001	....	....
Mean	+0.0022	−0.0004	−0.008	−0.004

The comparison appears quite decisively to place the lines of groups *d*, *sub-d*, and *e* at higher levels than those of group *b*.

QUANTITY OF ABSORBING VAPOR

The thickness of the shells of vapor to which lines of different intensities of an element owe their origin is a rather surprising deduction from the chart of distribution and the elevations given

[1] *Contributions from the Mount Wilson Solar Observatory*, No. 58; *Astrophysical Journal*, **35**, 10, 1912.

[2] *Astrophysical Journal*, **12**, 307, 1900.

[3] *Ibid.*, **15**, 97, 1902.

by Jewell. The iron lines of intensities 0000–10 are all below an elevation of 3500 km, giving an average thickness of 250 km for each intensity. For the lower levels, the average thickness is still less. The mean level of the shell of vapor in which the iron lines of mean intensity 2 originate is at an elevation of 250 km. As Jewell suggests: "The lower levels of the region of the chromosphere producing lines seen during totality are at least 200 or 300 and possibly 500 miles above the sun's surface. This will explain the absence of the smaller metallic lines in the flash spectrum."[1] Few lines of intensity 0 are reported by eclipse observers. In the lists examined there are only four of this intensity, so that the levels of lines of intensities 0000–0 would be within the 500 km of the sun's surface, corresponding to a thickness of some 125 km for each intensity.

The efficiency of the relatively thin shells of vapor in producing the Fraunhofer lines implies a greater quantity of vapor in the solar atmosphere than it has been customary to consider. From the small amounts that are effective in laboratory experiments in reversing the spectrum lines, it has been said that very minute quantities, thimblefuls, for example, were present in the sun's reversing layer. Very small quantities are effective for the lines of a given intensity for any element, but the absorbing centers effective for lines of different intensities of a given element are apparently not identical and appear to be allocated in successive spherical shells, so that the total quantity of any element, such as calcium, is much larger than necessary to produce any one line. Calcium is distributed throughout all levels. The weakest calcium line used in the present investigation is of intensity 1, and the pressure at the corresponding level probably exceeds 6 terrestrial atmospheres. An estimation of the quantity of calcium vapor in a column 1 cm square may be made, by assuming a reasonable proportion for the calcium content in the composition of the solar atmosphere at that level. Suppose it to be 1 per cent of the volume. The density of calcium is 40 times that of hydrogen. The partial pressure due to calcium vapor would be 60 g-dynes. The mass of the calcium content of the column $=60/27.6=2.18$ grams. The volume of

[1] *Publications U.S. Naval Observatory*, **4**, Pt. 4, App. I, 299, 1906.

this mass at 3000° C. and P = 1 atm. is 66.6×10^2 cc and is equivalent to a column 1 cm square and 67 m long, to be compared in absorbing power to the thin outer layer of calcium vapor in the arc. This quantity of calcium vapor in a vertical column of 1 square cm cross-section would mean, first, that complete absorption would probably occur for every line; second, that the light in a Fraunhofer line is due to the radiating vapor to which the line owes its origin; third, that the line appears dark because the temperature of the radiating layers are less than that of the source of the continuous background; and fourth, since the lower temperatures occur at the higher levels, that the lines originating in these levels show the strongest contrast with the background. This exposition of the formation of the Fraunhofer lines is that given by Abbot.[1] The great effectiveness of small amounts of vapor in producing reversals in the laboratory indicates that the effective layers in the sun's atmosphere need not be thick; and since the selective absorption varies directly with the intensity of a line, it follows that the effective layers would be at increasing elevations as the lines increase in intensity.

DISCUSSION OF RADIAL DISPLACEMENTS IN RELATION TO VARIOUS SOLAR PHENOMENA

The degree of dependence that can be placed upon the interpretation given in the present paper and the value of the results may be judged from the degree to which they harmonize with previously obtained data; from the manner in which they co-ordinate somewhat disconnected lines of solar work; from the additional light they throw on other investigations; and from the basis they furnish and the direction they indicate for further solar work. In the following sections the bearings of the results upon several lines of solar work will be discussed under the following headings: (1) radial displacements and eclipse results; (2) modification of spot lines as a function of level; (3) displacements at the sun's limb; (4) solar rotation and level; (5) magnetic field and level; (6) anomalous dispersion; (7) solar and terrestrial analogies.

1. *Radial displacements and eclipse results.*—In Table VI the lines for which Jewell[2] gives the elevations determined from the

[1] Abbot, *The Sun*, 1911. [2] *Loc. cit.*

eclipse plates are arranged in groups, the lines in which are approximately at the same level according to the chart of the distribution of the elements. The enhanced lines, as has been shown, are at about the level of other lines of two intensities greater, and this is taken into account in the grouping of the lines. Lines for which the flash lines are plainly compound are not included, such as λ 4481. This is identified by Jewell with iron lines of intensities 5 and 3 and with a Fraunhofer line of intensity 0 which he assigns to magnesium. The identification of this weak solar line with magnesium is somewhat doubtful, as the magnesium line is very characteristic of the spectra of early type stars and probably disappears before the solar stage is reached.

TABLE VI

HEIGHT ABOVE SUN'S LIMB AND RADIAL DISPLACEMENTS

Intensity 1–3 Mean Int. 2	Intensity 4–6 Mean Int. 5	Intensity 7–15 Mean Int. 9	Near Level of Vel. Inver.	Intensity 40	Intensity ——
200 *Ti* 100 *Ti*	800 *Ti* 900 *Ti*	3500 *Ti*	1500 *Ca*	8000 H_γ	15000 *Ca* K_3
100 *Cr* 150 *Zn*	600 *Fe* 1000 *Ti*	....	3500 *Sr*	....	....
200 *Y* 100 *Ca*	2500 *Ti* 1000 *Cr*	3000 *Ti*	....	....	....
100 *Ca* 150 *Ca*	1000 *Cr* 1000 *Cr*	1500 *Ba*	3000 *Mg*(*b*)	....	....
200 *Sr* 200 *Sc*	1000 *Fe* 1000 *Y*	800 *Fe*	1800 *Al*	....	....
200 *Fe* 100 *Mn*	....	1200 *Al*	....	....	....
150 *Cd* 150 *Zn*	....	1800 *Sc*	....	....	....
Means {150 mi. 240 km	1080 miles 1740 km	1970 miles 3100 km	2450 miles 4000 km	8000 miles 13000 km	15000 miles 24000 km
Radial displacement +0.025Å	+0.019 Å	+0.007 Å	−0.033 Å	−0.009 Å	−0.063 Å

From the comparison, it is very evident that large positive displacements are associated with low heights above the photosphere and large negative displacements with great heights, and that the general march of displacements follows the progression of heights for the intermediate elevations. It seems justifiable to draw the conclusion that the displacement of the Fraunhofer lines at the edges of the penumbrae of eccentrically located spots furnishes a method of sounding the solar atmosphere with considerable precision, a method of wide application and available whenever spots are on the solar surface.

In deducing the heights of levels from Jewell's paper the results

for one line were discarded. The line is λ 3694, of solar intensity 3, attributed by him to ytterbium and assigned a height of nearly 7000 km. If the displacements at the edges of the spot penumbrae are criteria of level, it would not be expected that this ytterbium line would reach so high a level in the solar atmosphere, since the level of its origin is near that of iron lines of intensity 00, and no lines of this intensity are reported by any of the five observers. In Jewell's report, the entry for this line is as follows:

Remarks	Chromosphere	Identification
Badly blurred	3694.4	3694.344 *Yb* 3

Possible identifications are, however, 3694.164, *Fe* 4, and 3695.194, *Fe* 5. Of the 37 lines of intensities 4 and 5 included in this investigation, 73 per cent are observed in the flash spectrum. It seems probable that the chromospheric line is not due to ytterbium alone but is coincident with the center of gravity of the three lines, which is at λ 3694.6, since the iron lines are not otherwise represented in this flash spectrum.

It is learned from Professor Campbell that there is a faint line at λ 3694.31 on the Lick Observatory plate of the eclipse of August 30, 1905. The small intensity of the line appears to negative an extremely great elevation for the same and to indicate that only a small amount of vapor is concerned in its production.

A comparison with eclipse results may be made by comparing the frequency of the appearance of a line in the flash spectrum with its radial displacement. On the assumption that radial displacements increase with depth, the more frequently occurring lines in eclipse spectra would show the smallest radial displacements. Such a comparison has been made with the eclipse results of Jewell,[1] Humphreys,[2] Frost,[3] Mitchell,[4] and Evershed.[5] From a comparison line by line through the region included by all the observers, the results are as follows:

Lines Observed by	Mean Radial Displacement
3 out of 5 observers	0.009 Å
1 or 2 out of 5	0.0023
None of the 5	0.0026

[1] *Publications U.S. Naval Observatory*, **4**, Pt. 4, App. I, 121, 1906.

[2] *Ibid.*, p. 252.

[3] *Astrophysical Journal*, **12**, 307, 1900.

[4] *Ibid.*, **15**, 97, 1902.

[5] *Philosophical Transactions*, **201** A, 457, 1903.

The results seem clearly in favor of the hypothesis that radial displacements are intimately connected with levels, and that the assumed variation with depth represents a real relationship.

In the preliminary report of the eclipse of August 1905 furnished to Abbot for his book *The Sun*, Mitchell says (p. 179): "It must be concluded that the flash spectrum is a reversal of the Fraunhofer spectrum, but with marked differences in the intensities of the two spectra." From the list of 92 lines in Mitchell's preliminary report, all lines not blends were selected for the comparison of the relative intensities in the two spectra. The results appear in Table VII, where the figures in parentheses give the number of lines involved. Lines of the heavy and rare elements, *Ba*, *Ce*, *La*, *Eu*, *Nd*, are used only in the right-hand end of the table.

TABLE VII

SOLAR AND FLASH INTENSITIES

	Elements									
	Fe, V, Co, Ti, Cr, Zr, ?							*Ba, Ce, La, Eu, Nd*		
Solar intensities	8	5	4	3	2	1	0	2	1	0–00
Flash intensities	5 (8)	2.5 (6)	1.5 (10)	2.8 (4)	1.5 (10)	0.6 (10)	0.8 (4)	2 (1)	4 (2)	1.8 (4)
Flash intensities×1.6	8	4	2.4	4.5	2.4	1	1.3	3.2	6.4	2.9

In view of the excellence of the eclipse spectrum obtained by Mitchell, the comparison leaves no doubt of the changed relative intensities. The intensities in the flash spectrum multiplied by the factor 1.6 for better comparison are in the third line. The sum of the solar intensities in the first part of the table is 23. The sum of the flash intensities in the corresponding last line is 23.6, but the distribution of intensity is quite different. It is evident that lines of solar intensity 0 are relatively stronger in the flash spectrum, and for the lines of the heavy elements the increased relative intensity is most striking; the lines of cerium and lanthanum of solar intensity 0–00 are as strong in the flash spectrum as other lines of solar intensity 4. It thus appears that relative depths of the effective layers may be a determining factor in the increased brightness.

From the point of view that the lines of the heavy and rare elements originate in thin shells of vapor lying below the effective layers of iron lines of the same intensities, it is clear that large changes in relative intensities of the lines should occur in the flash spectrum; for let us consider the thin low-lying layer in which the cerium lines of intensity 0 have their source, and the higher level in which iron lines of intensity 4 are produced. The cerium Fraunhofer lines are weak because of the high temperature of the vapor; the Fraunhofer lines of intensity 4 having their source in the higher layer are stronger because of the lower temperature of the vapor. In the flash spectrum, consisting of bright lines, the higher temperature of the low-lying layer and the low temperature of the high layer are conditions that will increase the brightness of the lines of low origin in comparison with those of higher levels. Mr. Evershed suggests that the more extensively diffused gases would give the stronger lines in the flash spectrum by reason of their greater radiating areas.[1] This would be the result if the whole depth of the solar atmosphere were effective in the case of all lines due to a widely diffused substance, but the relatively greater brightness of the flash lines of the very low-lying layers of cerium giving solar lines 0–00 compared to the flash lines corresponding to lines of solar intensity 4 would imply that the region effective in producing the stronger Fraunhofer lines did not include at the limb the whole depth of the widely diffused vapors, but was comparable in thickness to that of the low-lying vapor of cerium. It may be assumed that the lower portion of the widely diffused vapor is coincident with and at the same temperature as the cerium vapor. If the whole depth of the widely diffused vapor were effective in producing the flash lines corresponding to the line of solar intensity 4, one would expect the flash lines due to it to be stronger than those due simply to low-lying vapors. As they are approximately equal in intensity, it would appear that only a portion, and not the lowest portion, of the widely diffused vapor was effective in producing either the flash lines or the Fraunhofer lines.

Since the above paragraph was written and just as the manuscript is ready for the press, some data from the unpublished results

[1] *Philosophical Transactions*, 197 A, 393, 1901.

of the Lick Observatory eclipse observations have been placed at the writer's disposal through the kindness of Professor Campbell. These refer to the eclipses of May 28, 1900, and August 30, 1905. In the latter case they include both the fixed and moving plate results. The increased relative intensity of the lanthanum lines appears here also. The mean solar intensity of the two lanthanum lines λ 4486 and λ 4123 is 1.5. The mean flash intensity is 2.1. As a basis of comparison the three strongest solar lines in this region may be conveniently used. The mean solar intensity of the cobalt line λ 4086 and of the two iron lines λ 4087 and λ 4123 is 3.7; their mean flash intensity is 1.4, so that the relative intensity of the lanthanum lines increases from 0.4 of the solar intensity of the comparison lines to 1.5 times the flash intensity of the same lines. Here, again, one seems constrained to conclude either that the thin low-lying layers of lanthanum vapor are more effective in producing bright lines than the whole thickness of the widely diffused iron vapor, including the very high-temperature portion coincident with the stratum of lanthanum vapor, or that only a portion of the iron vapor—the effective layer—is concerned in producing these iron lines, and that the comparison should be between the effect of the admittedly thin stratum of lanthanum vapor and that of the suggested effective layer of iron vapor comparable in thickness to that of lanthanum, as was done above in the case of cerium.

The same relatively great intensity of the reversals of the weak Fraunhofer lines is a very marked feature of the flash spectra photographed without an eclipse by Hale and Adams.[1] In their Table II covering the green region, 80 per cent of the identifications are with solar lines of intensities 000 and 0000 which are assigned to carbon or cyanogen. As has been pointed out, the effective level of the carbon or cyanogen lines given by the radial displacements is very low, and the conditions in this low layer of high temperature are particularly favorable to the production of strong bright-line spectra. The prevalence in these spectra of the reversals of the weak solar lines makes it probable

[1] *Contributions from the Mount Wilson Solar Observatory*, No. 41; *Astrophysical Journal*, **30**, 222, 1909.

that Hale and Adams were observing at a lower level than that generally reached in eclipse observations, and lends additional weight to the interpretation based upon effective levels.

Some observations by Sir Norman Lockyer[1] upon the features of the flash spectrum taken at different elevations seem to bear directly upon the question of effective levels:

In the spectrum taken very near the moment of second contact, representing that of lower strata with the spectra of the higher one superposed, the metallic arcs are relatively short and very bright, while in later photographs representing the spectra of successively higher strata free from admixture with lower ones, the metallic arcs are relatively feeble. This is also indicated in another way by the varying effects seen over the tops of lunar mountains and through indentations in the moon's limb. Some of the lines are seen to be much brighter in the upper strata than in the lower, such lines showing no increase in brightness at the points where lower strata are revealed through lunar valleys. Chief among these lines are those of hydrogen, helium, and calcium (H and K).

The relative brightness of the low-level metallic lines near the moment of contact, their weakening as successive portions of the solar atmosphere are covered by the moon, their behavior over the tops of the lunar mountains and in the intervening valleys, and the absence of increased brightness on the part of the high-level lines of calcium and hydrogen where lower regions of the solar atmosphere are revealed between the lunar mountains, all seem to limit the production of the lines to rather definite regions.

2. *Modification of spot lines as a function of level.*—In a paper summarizing the results of the study of the Mount Wilson sun-spot spectra,[2] Mr. Adams concludes that the weakening and strengthening of lines in the sun-spot spectrum may best be accounted for on the basis of a reduced temperature in spots. As the temperature would vary with elevation, the weakening and strengthening of the lines would be a function of level and bear a direct relation to their radial displacements. From the large amount of quantitative material in the paper referred to, the data respecting the character of the spot lines in Table VIII have been taken. In the last column are given the corresponding radial displacements.

[1] *Philosophical Transactions*, 197 A, 202, 1901.

[2] *Contributions from the Mount Wilson Solar Observatory*, No. 40; *Astrophysical Journal*, **30**, 86, 1909.

The H and K lines are difficult to classify, and by some observers have been considered as strengthened lines, since the central portion over spots appears generally brighter on the dark background of the wings. The apparent brightening, however, of the central portion is an effect of contrast due to the strengthened wings, as shown in a previous paper.[1] In the case of sodium D_1 and D_2, the wings are enormously strengthened. Unlike the H and K lines of calcium, the centers of D_1 and D_2 are simply the densest portions and are bounded by wings which are greatly strengthened and, as a result, widen the central portion on the two edges. The cores of

TABLE VIII

Lines		Character in Spots				Radial Displacement
Calcium	H and K	Central portion weakened. Wings greatly strengthened				−0.063 Å
Hydrogen	H_α	Weakened 40 to 25				− .050
Hydrogen	H_γ	Greatly weakened 20 to 4				− .033
Hydrogen	H_δ	Very greatly weakened 40 to 1				− .005
Magnesium	b_1 and b_2	b_1 no change; b_2 slightly strengthened				− .012
Sodium	D_1 and D_2	Cores widened; wings enormously strengthened				−0.006
		No. of Lines	No Change	Weakened	Strengthened	
Iron	10–30	9	67 per cent	33 per cent	0 per cent	0.000
Iron	5– 8	62	31	13	56	+ .015
Iron	2– 4	58	24	9	67	+ .024
Level of *Fe* 1 to *Fe* 000, weak *Ti* and *Na* lines		16	0	0	100	+ .031
Vanadium 00		2	0	0	100	+0.035

the lines, originating at the highest levels, upon which the measures of this paper are based, may still be unstrengthened or even weakened. As a whole, it is apparent from the table that weakening goes with high levels and strengthening increases with the depth. This is markedly true for the lines of moderate and low intensity, in which the proportion of strengthened lines increases and of weakened lines decreases systematically with the increase of radial displacements. As indicated above, the H and K lines of calcium and the D_1 and D_2 lines of sodium are probably not exceptions to

[1] *Contributions from the Mount Wilson Solar Observatory*, No. 54, 29–31; also Plate III*a*; *Astrophysical Journal*, 34, 131, 1911.

the general march of the phenomenon. When Mr. Adams' results for the lines of medium and low intensities of the other elements are considered, the same large percentage of strengthened lines is shown.

The weakening of the very strong lines follows from their origin in the high region where the cooling effect of the spot vortex has little effect on the temperature of the vapors and the lines are changed but slightly, if at all, in absolute intensity, but the continuous background against which they are seen is decreased in intensity so that by contrast they appear weakened.

In the case of hydrogen the weakening increases with the depth. Adams says:

> There is some evidence to indicate that the lines are most weakened in spots in which the bands and flutings are especially strong. If such is the case, it would tend to show that a large part of the hydrogen in spots goes to the formation of the hydride compounds, thus producing weakening of the hydrogen lines.

The hydride compounds are formed in the cooler regions of the umbra. The chemical action would spread upward and involve the lower levels of the overlying hydrogen more than the upper, thus reducing the intensities of the hydrogen lines in the inverse order of the elevations of their effective levels.

A cause working in the same direction is suggested by Abbot:[1]

> Owing to the lower temperature, the energy spectrum, that is the continuous spectrum background, in sun-spots as at the sun's limb, is weaker in the violet as compared with the red than is the ordinary solar spectrum. Thus, in spots, the radiation in the violet hydrogen lines approaches more nearly the brightness of the spectrum background than that in the red lines. Hence, the comparatively greater weakening of the shorter wave-length hydrogen sun-spot lines follows.

The general strengthening of the lines of the reversing layer results from the lower temperature in and directly above the spot umbrae, and the increased strengthening with depth indicates that the temperature decreases from the upper level to the lowest level accessible to the spectroscope.

The orderly march of the change of intensity of the lines in spots with the increase of depth of the corresponding lines in the

[1] *The Sun*, p. 269, 1911.

reversing layer at the edge of the penumbrae, indicated by the increasing radial displacements, points to the probability that the relative levels in the two cases are the same, that the absolute levels may not differ greatly, and that the lowest depths in sun-spots from which light affected by selective absorption reaches the surface of the sun is not greatly below the lowest levels of the reversing layer.

3. *Displacements at the sun's limb.*—From an extended investigation of the displacements of the spectrum lines at the sun's limb Mr. Adams concluded,[1] in agreement with Halm[2] and Fabry and Buisson,[3] that pressure is the determining factor in producing the displacements. It is of interest to consider such displacements from the point of view of the vertical distribution of the effective layers given by the data of the present paper. It appears that the effective levels are quite different for lines of different intensities, and are surprisingly shallow in the lower reversing layer and very thick in the upper chromosphere. Taking the elevations from Jewell's eclipse results, the lower levels are about 125 km thick on the average. The first 12 levels average about 250 km in thickness, while from the inversion level to H_γ it is 9000 km and from H_γ to K_3 it is 12000 km. If a given line originates in a comparatively thin shell, the path of light in the lower portions of the shell will be greatly lengthened at the limb; and if there is much difference in the pressures between the upper and lower levels of the shell, the line will have an increased wave-length and the increase will be on the red edge of the line. In the case of lines at very high levels the pressure throughout the shell is less than 1 atmosphere, so that the lines originating in these levels would show very small pressure displacements at the limb; and as the high-level vapors are descending over the general surface as shown for *H* and *Mg* and *Na* by Perot and Lindstedt,[4] and for *Ca* by St. John,[5] such

[1] *Contributions from the Mount Wilson Solar Observatory*, No. 43; *Astrophysical Journal*, **31**, 30, 1910.

[2] *Astronomische Nachrichten*, **173**, 272, 1907.

[3] *Comptes rendus*, **148**, 174, 1909.

[4] *Comptes rendus*, **153**, 1367, 1911; **154**, 326, 1912.

[5] *Contributions from the Mount Wilson Solar Observatory*, No. 48; *Astrophysical Journal*, **32**, 36, 1910.

lines would show an apparent decrease in wave-length near the limb, or a small shift to the violet. In the case of lines at lower levels, the displacements toward larger wave-lengths should increase with lowness of level; but at very low levels where the differences in the pressure, and consequently the differences in density, between the upper and lower boundaries of the effective layers become large, the scattering of the light is greater and reduces the intensity from the lower portion of the effective levels; that is, the effective levels are higher than they would be without scattering. It follows that for very high levels the displacements should be negative, for lower levels positive and increasing, until a depth is reached in which the effect from scattering balances the increased effect from pressure and the displacements remain more nearly constant. At the lowest depths the cutting-off of the very deep-lying portion of the effective levels by scattering might well result in zero displacement, or even displacements to the violet or a complete obliteration of the line. In Table IX results for lines of different levels are shown. The levels are taken from the chart of vertical distribution, and under high and very high levels are included all the lines studied by Adams; under intensities 1 to 7 are included only the unenhanced lines of iron, and under the lowest level only the lines of barium, cerium, and lanthanum that according to the chart fall at this low level.

The figures in parentheses indicate the number of lines upon which the data are based. The march of the phenomenon is strikingly what would be expected. Mr. Adams also found that the displacements increased with wave-length. If the comparison be made between iron lines belonging to the same pressure group, *b* of iron for example, as can now be done since the work of Gale and Adams on the spectrum of iron under pressure through a wide range of wave-lengths, the agreement between the displacements at the limb and the pressure-shifts found in the laboratory shows with great clearness.

For 8 lines of intensity 5 near λ 4150 the displacement is 0.005 Å
" 5 " " " 5 " λ 6300 " " " 0.010

This shows more clearly still when the differences in level are taken into consideration, as lines in the red are about 1 intensity

TABLE IX

DISPLACEMENTS AT THE LIMB (ADAMS)

	Levels							
	Fe 0	*Fe* 1–2	*Fe* 3	*Fe* 4	*Fe* 5	*Fe* 6–7	*Fe* 8–20	Above Level of Inversion
Element..........	*Ba, Ce, La*	*Fe*	*Fe*	*Fe*	*Fe*	*Fe*	*Fe, Si, Ti*	*Al, Ca, H, Mg, Na*
Displacements..........	0.000 (10)	0.005 (18)	0.005 (20)	0.006 (21)	0.007 (20)	0.007 (28)	0.004 (16)	−0.002 (14)

below, and those in the violet about 1 intensity above, the mean level for lines of the same intensities. The lines at λ 4150 correspond to the general level of intensity 6, and those at λ 6300 to the level of intensity 4. So that, with no increase of displacement with wave-length, the displacements of lines of lesser wave-lengths to those of the larger wave-length would be in the ratio of 7:6 instead of 5:10, as they are, which indicates that between the displacement of λ 6300 and that of λ 4150 the real ratio is about 2.3:1. The pressure displacements in the case of iron lines vary as the cube of the wave-length, according to the results of Gale and Adams already referred to; hence between the wave-lengths considered the ratio between the pressure-shifts is 3.4:1. In view of the rise in the level of the effective layers near the limb due to scattering and selective absorption, which tends to reduce the displacements caused by pressure, unequally at different depths, only a qualitative agreemênt would be possible between the pressure-shifts in the laboratory and the displacements between center and limb.

When the displacements of the unenhanced lines of titanium are compared with those of iron at corresponding levels the ratio displacement of iron to displacement of titanium is 2.1:1. When displacements under pressure are compared it is 2.0:1.

Mr. Adams found that the enhanced lines gave larger displacements than the unenhanced. He discussed the suggestion made by Mr. Evershed that the enhanced lines are due to the ascending currents of hot gases represented by the granulations, but said:

> Another possible explanation of the larger displacements given by the enhanced lines must not, however, be overlooked. This is the possibility that the enhanced lines may show larger shifts under pressure in the laboratory.

Data are now available for a comparison between pressure-shifts in the laboratory and the displacements between limb and center for identical lines, by considering the lines common to the table of limb-center displacements given by Adams[1] and the list of pressure-shifts of titanium lines given by Gale and Adams.[2] Table X shows the results.

[1] *Contributions from the Mount Wilson Solar Observatory*, No. 43; *Astrophysical Journal*, **31**, 31, 1910.

[2] *Contributions from the Mount Wilson Solar Observatory*, No. 58; *Astrophysical Journal*, **35**, 10, 1912.

The practically identical ratio between pressure-shifts and displacements between limb and center points to an intimate relation between the two phenomena.

The result of the discussion from the point of view of this paper is that pressure can with great probability be assigned as the predominating factor in the phenomenon, and that the effect of pressure is modified by differences of level, is lessened by scattering in the lower levels, is entirely overcome at the lowest levels, and at the highest levels the general downward movement of the vapors masks or reverses the pressure effect.

TABLE X

ENHANCED AND UNENHANCED TITANIUM LINES

Lines Common to Both Lists	Displacements	
	8 Atmospheres	Limb—Center
17 enhanced.........	0.034 Å	0.0046 Å
36 unenhanced.......	0.023	0.0030
Ratio enh. to unenh..	1.48	1.53

4. *Solar rotation and level.*—The extended series of measurements made by Mr. Adams and Miss Lasby[1] furnishes a large amount of material for an investigation of level when considered in connection with the general results of this paper, which point to a mean level for the lines of the elements of a given intensity. In making the comparison between the two series of measurements, it is to be borne in mind that the results in the case of the solar rotation are based upon repeated measurements of the same lines, while the results of the present paper refer to groups of lines, and it is therefore to be expected that individual lines will occasionally depart from the mean results of a group. The differences between the results for different lines in the case of the rotation measurements, if the differences are real, mean that the displacements between the two limbs of the sun have been measured to the fourth decimal place. To obtain data of the maximum weight, the mean angular velocities for all latitudes from 0°–45° and from

[1] *Publications of the Carnegie Institution of Washington*, No. 138.

50°–80° have been formed in the case of each line. All the lines, 15 in number, that are common to both series given by Adams which are not blends are considered in the course of the comparison. In Table XI the lines used are grouped according to the levels indicated by radial displacements.

TABLE XI

ANGULAR VELOCITY OF SOLAR ROTATION AND RADIAL DISPLACEMENTS

Lat.	H_a	λ4227	*Fe* 3 (1)	*Fe* 2 (4)	*Fe* 1 (1)	*Cn* (1–2)	*La* 2
0°–45°	14°65	14°44	14°00	13°95	13°92	13°78	13°83
50 –80	14.39	13.93	11.72	11.70	11.68	11.48	11.36
Radial displacement	−0.050	−0.002	+0.019	+0.024	+0.026	+0.026	+0.028

The arrangement in order of depth given by radial displacements is the same as that given by the solar rotation values on the hypothesis that large negative values of radial displacements denote high elevations, that large positive values refer to low levels, and that the angular velocities increase with the elevation in the solar atmosphere. The lines of nickel and chromium are at the same general level as the lines of iron of the same intensity, and those of titanium are at a somewhat higher level. The results for these elements are in Table XII. For 12 out of the 15 lines the order

TABLE XII

ANGULAR VELOCITIES FOR LINES OF SAME LEVEL

Lat.	*Fe* 1	*Ni* 1	Mean	*Fe* 2	*Cr* 2	*Ti* 1	Mean
0°–45°.........	13°92	13°89	13°91	13°95	13°96	13°90	13°94
50 –80	11.68	11.70	11.69	11.70	11.70	11.72	11.71

of the levels given by the two investigations is in agreement. There remain three cases where the indications are contradictory. The enhanced line of titanium, λ4290 of intensity 2, gives rotation values that are consistently low, and the two lines of manganese, λ 4257 and λ 4266 of intensity 2, values that are consistently high. In Table XIII the rotation values of these lines are compared with those of *Fe* 2.

TABLE XIII

EXCEPTIONAL ANGULAR VELOCITIES

LAT.	*Mn* 2		*Fe* 2	*Ti* 2
	λ 4257	λ 4266		λ 4290
0°–45°..................	14°04	14°00	13°95	13°85
50 –80	11.90	11.88	11.70	11.57
Radial displacements......	+0.027	+0.028	+0.024	+0.015

These lines are in the violet region of the spectrum where the lines are closely packed, and it is never certain that a given line is not a blend. If the titanium line is a blend, its low rotation value would be explained, as the components of a line of intensity 2 would be at a very low level. As to the high level of this line indicated by the small radial displacement, this follows from the behavior of enhanced lines in spots. In the case of enhanced lines, as has been shown, the relative levels effective in radial displacements in spot penumbrae are probably not the same as those effective in solar rotation displacements, the effective layer being relatively higher in spots than in the general reversing layer. From this point of view, the low rotation value found by Adams and the small radial displacements shown are not inconsistent.

In the case of the manganese lines the difficulty caused by their higher angular velocity would be increased if they are blends, but the large radial displacements would be explained. The radial displacements depend upon only 6 or 7 plates, for which the mean deviations are much higher than the average. As has been said, the rotation values emphasize the character of an individual line, while, in the case of the radial displacements, the variation of a single line from the mean might well be accidental. There are a number of cases in which individual lines show large departures from the mean, but the data at present are too meager to establish a variation in the case of an individual line. In the 1908 series Mr. Adams added the line λ 4233, intensity 4, which Rowland attributes to *Mn-Fe*. It is conspicuous in eclipse spectra, but yields the same rotation value as the reversing layer which is based upon lines of intensity 2. If it is a blend of manganese and iron,

its components would be at the mean level of lines of intensity 2 and the agreement with the mean for the reversing layer would not be surprising. If one or both components are enhanced, its appearance in the flash spectrum would be expected from the effect upon the enhanced lines due to decrease of pressure following the rise in level of the effective layers just outside the border of the solar disk.

The value that Adams found for the reversing layer was determined from lines of mean intensity 2. As shown by radial displacements, there are lines suitable for rotation measures of still lower level than *La* 2, which gave the lowest angular velocity. For example:

La 1, displacement +0.029 Å at the level of *Fe* 0
Ba 2 and *Yb* 3, displacement +0.031 Å at the level of *Fe* 00
Nb 1, displacement +0.035 Å at the level of *Fe* 000

It is possible and quite probable that, if Mr. Adams had used these lines, he would have found a still lower angular velocity. There are some data for lines of higher level than *Fe* 2. In the 1908 series Mr. Adams added 2 calcium lines of intensity 4 to the observing list. Perot used 4 lines of mean intensity 7. Dunér and Halm both used the *Fe* lines λ 6301 and λ 6302 of intensities 7 and 4. Story and Wilson used 9 *Fe* lines of mean intensity 4, including λ 6301 and λ 6302. The comparison in the case of the two calcium lines of intensity 4 that Mr. Adams used in 1908 is made with the means of that series in which the mean intensity of the lines is 2, and shows in Table XIV.

TABLE XIV

ANGULAR VELOCITY AND INTENSITY

Lat.	*Ca* 4	Rev. Layer
0°–45°	13°99	13°98
50 –80	11.34	11.27
Radial displacements .	+0.019	+0.024

The difference in angular velocity is slight and, if the case stood alone, it would be negligible and hardly deserve consideration; but the probability of its being real is strengthened when it is con-

sidered that, of the 13 latitudes, 3 only give negative results and the mean residual for the 13 latitudes is +0.03, and by the fact that it is in harmony with the more decisive cases given in this paper. Table XV gives the data for comparisons of Adams' results with those of Perot,[1] Dunér and Halm, and Story and Wilson. The mean of the two series of Mr. Adams are taken from Table 30, *Publications of the Carnegie Institution*, No. 138. The values for Dunér and Halm are those given by Pringsheim,[2] and the Story and Wilson values are from their paper.[3] The means of these three determinations are used for the comparison with the means of the two series by Mr. Adams and Miss Lasby.

TABLE XV

ANGULAR VELOCITIES FOR LINES AT DIFFERENT LEVELS

Lat.	Perot	Dunér	Halm	Story and Wilson	Mean Dunér, Halm, Story and Wilson	Adams and Lasby	Mean—Adams and Lasby
0°2....	14°8	14°8	14°6	14°8	14°7	14°5	+0°2
15.0....	....	14.5	14.3	14.5	14.4	14.3	+0.1
29.7....	....	13.9	13.7	14.0	13.9	13.7	+0.2
45.0....	13.2	12.8	13.2	13.3	13.1	12.8	+0.3
59.6....	....	11.5	12.6	12.4	12.2	11.9	+0.3
75.9....	....	10.7	12.3	11.2	11.4	11.3	+0.1
Intensities...	7	6	6	4	5.3	2	
Radial displacements.	+0.015	+0.018	+0.018	+0.021	+0.019	+0.024	

The lines are not all in the region of the spectrum covered by this investigation and the radial displacements indicated are for iron lines of equal intensities. The mean values found by Dunér, Halm, and Story and Wilson are of such weight that when they are compared with the results found by Adams and Miss Lasby the indications of higher levels in the case of these heavy iron lines are very strong. The angular velocities found by Perot, depending, however, upon much slenderer data, point in the same direction.

The comparison of solar rotation values with radial displacements indicates two methods at hand for determining the relative

[1] *Comptes rendus*, 147, 340, 1908.

[2] *Physik der Sonne*, p. 60, 1910.

[3] *Monthly Notices*, 71, 686, 1911.

levels in the solar atmosphere at which the Fraunhofer lines originate. The agreement between the results given by the displacements at the two edges of the penumbrae of spots due to motion of the vapors radial to the vortex axes and the displacements at the limb due to rotation indicate that the distribution in the neighborhood of sun-spots is, in general, the same as in the undisturbed regions of the solar atmosphere, and suggests a wider program for both methods of investigation. There is a great difference in the ease of application of the two ways of sounding the solar atmosphere. The differences in the angular velocities of the succeeding levels are difficult to establish by the displacements due to solar rotation. In the results of Mr. Adams the tangential velocities in latitude 45° for lanthanum and the reversing layer differ by 0.02 km per second. To detect this difference by determining the displacements between the east and west limbs of the sun requires measurements to 0.0006 Å. The radial displacements differ, however, by 0.0025 Å per unit intensity, so that measurements of differences of level by this means are well within the range of many instruments.

The bearing of the radial motion phenomena upon the question of level raised by the rotation values found from different lines and elements was not fully realized during this investigation, and appeared clearly only when the observations were finally reduced and the data assembled. The confirmation of the solar rotation results found by Mr. Adams and Miss Lasby coming from such an apparently unrelated investigation is of peculiar interest and importance in view of the negative results that follow from the solar rotation investigations of Hubrecht[1] and Plaskett and DeLury,[2] who observed no differences that they considered due to different elements and lines. If, however, the differences in radial displacements are rightly interpreted as indications of differences in level, certain differences in level appear to be established, for the radial displacements of the lines differ so greatly upon a given plate that exact measurement is not necessary to fix the fact of systematic differences in the direction and the amount of the displacements for lines differing sufficiently in intensity.

[1] *Monthly Notices*, **73**, 5, 1912.

[2] *Astrophysical Journal*, **37**, 73, 1913.

That a difference exists between the angular velocity of the high-level hydrogen and that of the reversing layer seems clearly shown by the accumulated observations. The values found spectrographically from the H_α line by Adams and Perot are respectively 15°0 and 15°2. From a long-enduring dark flocculus Evershed determined an angular velocity of 15°1, and from still richer observational material Deslandres and d'Azambuja obtained the value 15°0 for the absorption markings upon H_α spectroheliograms. The equatorial values found for the reversing layer are, Dunér 14°8, Halm 14°6, Adams 14°5, Story and Wilson 14°8, Hubrecht 13°2, Plaskett and DeLury 14°2. Since the lowest value determined from the H_α line is greater than the highest found for the reversing layer, the data seem to establish the existence of a difference in rotation associated with a wide difference in level and to make it probable that the differences that have been observed within narrower ranges of level are real. The small deviations in rotation results which Plaskett and DeLury are inclined to consider accidental or personal have in the large differences in radial displacements a basis of probability independent of the rotation measurements by Mr. Adams and Miss Lasby, which taken separately show consistent differences between certain lines and elements.

The determination of angular velocities from the rotation period of spots and flocculi furnishes additional data with which the results of the present investigation may be compared. The combined data are given in Table XVI. The values for the angular velocities in the cases of H_α, *Ca* 4227, *La*, and the reversing layer are based upon the data given by Mr. Adams in *Publications of the Carnegie Institution*, No. 138. The data for the H_δ flocculi and for the H_2 flocculi are from Mr. Hale's "Preliminary Note on the Rotation of the Sun as Determined from the Motions of the Hydrogen Flocculi."[1] The spot values are the means of the determinations by Carrington, Spörer, and Maunder, from the original papers. The values for the K_3 line of calcium are from my paper "On the General Circulation of the Calcium Vapor."[2]

[1] *Contributions from the Mount Wilson Solar Observatory*, No. 25; *Astrophysical Journal*, 27, 219, 1908.

[2] *Contributions from the Mount Wilson Solar Observatory*, No. 48; *Astrophysical Journal*, 32, 36, 1910.

There are two methods of comparing the angular velocities determined from different objects and elements on the sun in order to determine the relative levels. The rate of change in angular velocity with latitude may be used as a criterion, and also the comparison of the absolute values of the observed velocities. In the case of spectrographic determinations in which the proper motions play a very subordinate part and in which repeated determinations reduce the accidental errors of observation and measurement to a minimum, the variation with latitude is without doubt the more reliable criterion; but when the objects under observation are

TABLE XVI

ANGULAR VELOCITY AND LEVEL

Latitude	St. John K_2	Adams H_α	Hale H_δ Floc.	Adams *Ca* 4227	Hale H_2 Floc.	Kenwood-Yerkes H_2 Floc.	Adams		Spot Means
							Rev. Layer	*La*	
0°.....	15°5	15°0	14°6	14°9	14°42	14°61	14°54	14°50	14°40
5.....	....	....	....	....	14.38	14.50	14.51	14.47	14.38
10.....	....	....	....	....	14.32	14.36	14.43	14.39	14.31
15.....	15.4	14.9	....	14.8	14.28	14.20	14.31	14.24	14.20
20.....	....	....	....	....	14.27	14.11	14.13	14.06	14.06
25.....	....	....	....	....	14.17	13.91	13.91	13.82	13.89
30.....	15.3	14.7	....	14.3	13.98	13.78	13.67	13.54	13.69
Means..	15.4	14.8	14.6	14.7	14.26	14.20	14.22	14.17	14.13
0°—30°.	0.2	0.3	....	0.6	0.44	0.83	0.87	0.96	0.71
Radial displacement.	−0.063	−0.050	−0.005	−0.002	−0.044		+0.025	+0.028	....

subject to large proper motions, as in the case of spots and flocculi, the relation between the angular velocity and the latitude cannot be determined with a high degree of precision. Mr. Maunder calls attention to the great range in the angular velocities given by the spots within a five-degree zone. The rotation periods within such a zone differ by more than twice the greatest difference between the means of the zones, and for latitudes greater than 25° there is slight indication of grouping of the rotation values about a mean. It is precisely the values dependent upon the extreme latitudes of the spot and flocculi regions that are of importance in

determining the law of variation with latitude. In zones where spots and flocculi are sufficiently numerous, the effect due to proper motion may in a measure be eliminated. In Table XVI both methods of considering the data are indicated. The mean angular velocities refer to no one latitude, but in the means the effects of accidental errors are lessened for latitudes where spots and faculae are less numerous. The numbers in the line $0^\circ - 30^\circ$ give the equatorial acceleration in passing from $\pm 30^\circ$ to the equator. The bottom line shows the radial displacements for the corresponding lines, and these furnish a third criterion of level. In regard to some of the lines and objects, the deductions from the data appear clear and well founded. The high levels of the K_3 line of calcium and the H_α line of hydrogen and their relative levels are shown by the concurrent evidence of all three criteria: high angular velocity, small equatorial acceleration, and large radial displacement. The high angular velocity for H_α, and the small equatorial acceleration have been confirmed by Perot.[1] The exact relative level of the H_δ line of hydrogen is uncertain, but all the evidence indicates a high level for its origin, but not so high as for the H_α line. In a preliminary investigation of the sun's rotation by the displacements of the hydrogen lines Mr. Adams[2] included the H_γ and H_δ lines. Of the results he says:

> There seems to be some tendency for H_α to give larger values than those furnished by the other two lines. Until additional material, however, is available, particularly for H_γ and H_δ, it is hardly justifiable to consider this difference in velocity real.

Mr. Hale[3] says of the results for the hydrogen flocculi taken with the H_δ line:

> The hydrogen flocculi, however, show no systematic variation of velocity with latitude. As already remarked, the hydrogen measures are less reliable than those of calcium, because of the inclusion of a less number of flocculi, larger proper motions, and more rapid changes of form. We may therefore take the mean value for ξ for all zones ($14\overset{\circ}{.}6$) as a provisional determination of the daily motion of the hydrogen flocculi.

[1] *Comptes rendus*, **151**, 430, 1910.

[2] *Contributions from the Mount Wilson Solar Observatory*, No. 24; *Astrophysical Journal*, **27**, 213, 1908.

[3] *Loc. cit.*

The H_δ flocculi upon which measurements were made were well distributed in latitude so that the weights for the high and low latitudes are quite comparable, and the absence of systematic change in angular velocity with latitude is an indication of high weight in assigning the level. The radial displacement of -0.005 Å, shown by the H_δ line, points also to a high level. This value, however, is affected by large accidental errors. The line is so nearly coincident with an iron line that the measures are difficult, particularly so in the case of radial displacements, as the two lines are displaced in opposite directions, and the absolute displacements differ on different plates so that the appearance of the line changes greatly. There is no doubt concerning the sign of the displacement. Its numerical value, however, is probably too small. The radial displacement of H_γ is -0.033 Å, but H_δ is the stronger of the two lines, and in the preliminary paper by Adams the measurements show a rotation value for H_δ between the values for H_α and H_γ, from which a large negative displacement would be expected. The high level of the source of the line λ 4227 of calcium is shown by Mr. Adams' rotation measures and by the radial displacement, but its level with reference to H_δ is uncertain.

It will be noticed that the value for the H_2 flocculi given by the Mount Wilson plates are considered by themselves, and a higher level assigned to them than that indicated by the Kenwood and Yerkes measures which were made upon the large flocculi or portions of flocculi that are the striking features of calcium spectroheliograms. The Mount Wilson measurements were made upon the minute flocculi which are more widely distributed in latitude and possibly at a higher level. In my investigations of the movements of calcium vapor over the solar surface it appeared that the vapor producing the bright K_2 components was rising over the general surface, but not over the large bright flocculi in the neighborhood of spots. It was suggested that the rise over the general surface might occur mainly over the granulations, in which case the minute flocculi, the granulations of the spectroheliograms, would be the tops of the rising columns and a phenomenon of higher level than the more quiescent masses forming the larger flocculi. The high level of the flocculi on the Mount Wilson plates is indi-

cated by the small change of angular velocity with latitude. This indication is of weight in this particular instance, because the points in the extreme latitudes were relatively numerous, and the equatorial acceleration differs so widely from that of the reversing layer that, allowing a wide margin of error, the indicated level would still be high. The comparison by means, which tends to decrease the effects due to accidental errors in the extreme latitudes, shows a higher average velocity and therefore also a higher level than for the reversing layer. The level indicated by the radial displacement, −0.044 Å, is higher than would be inferred from the numerical values of the angular velocities, but not higher than would be consistent with the small change with latitude. The measurements of the radial displacements of the bright reversal are difficult and uncertain. They refer to the middle or the center of gravity of the line. The settings were made upon the violet and red components and the wave-length of the center of the line was determined by the method suggested by Adams.[1] The great width of the K_2 line implies an effective layer of great thickness within which the velocity radial to the axis of the solar vortex would vary greatly. In the case of the Mount Wilson spectroheliograms the dispersion of the spectroheliograph and the width of the second slit were of an order to allow the light from the entire width of the line to reach the plate. The center of the line was obliterated by the K_3 absorption line, so that the effects due to the edges of the line which are produced at a greater depth are emphasized in the spectroheliograms. In the case of the Kenwood and Yerkes measurements by Mr. Fox upon large flocculi, the level indicated by the equatorial acceleration is slightly above and that indicated by the mean of the velocities slightly below the reversing layer, and the relatively quiescent state over the large faculae in the neighborhood of spots would suggest that the level is near the upper portion of the general reversing layer. It seems probable, therefore, that these large flocculi belong rather to the upper reversing layer than to the chromosphere.

The measurements made by Mr. Adams and Miss Lasby upon

[1] *Contributions from the Mount Wilson Solar Observatory*, No. 6; *Astrophysical Journal*, **23**, 45, 1906.

the lanthanum line, when reduced by a least-squares solution, yield an empirical formula that may be compared with that obtained by them from the whole series.

$$\xi = 10^\circ\!.68 + 3^\circ\!.82 \cos^2\phi \text{, lanthanum}$$
$$\xi = 11.04 + 3.50 \cos^2\phi \text{, mean of whole series}$$

The measurements from which these formulae are derived were made upon identical plates, including 436 exposures, distributed through 80° of latitude. In view of the probable absence of differing systematic errors the following comparisons are striking.

TABLE XVII

ANGULAR VELOCITIES OF REVERSING LAYER AND LANTHANUM

	Latitude							Radial Displacement
	0°	15°	30°	45°	60°	75°	90°	
Rev. layer....	14°.54	14°.31	13°.67	12°.79	11°.92	11°.27	11°.04	+0.025Å
Lanthanum...	14.50	14.24	13.54	12.59	11.64	10.94	10.68	+0.028
Rev. layer—*La*.........	+0.04	+0.07	+0.13	+0.20	+0.28	+0.33	+0.36	−0.003

The level of the origin of the lanthanum lines is shown, by its low rotation value, large equatorial acceleration, and large radial displacement, to be below the level of the reversing layer given by lines of solar intensity 2.

The level of the spots given by a comparison latitude by latitude is below the reversing layer, while that indicated by the equatorial acceleration is above, as Mr. Adams has shown. The latter criterion depends for its value upon the measurement of spots in high and low latitudes, where it is doubtful whether the results have been or can be within many years sufficiently numerous to eliminate the influences of great proper motions. In view of the small differences in angular velocities, the level of the spot umbrae appears to be not far below the reversing layer studied by Mr. Adams. As deeply into the sun as observations extend, the angular velocity decreases with depth, and for a great difference in level, marked differences between the angular velocity of spots and reversing

layer would be expected in view of the large mass of data relating to the latitude zones in which spots are numerous.

In Wilsing's theoretical discussion of the law of the sun's rotation[1] he concludes that owing to internal friction the variation of angular velocity with latitude diminishes as the center of the sun is approached, until a surface is reached the particles of which rotate with sensibly constant angular velocity about a common axis. Limiting the comparison to spectrographic determinations, in which the influence of proper motion is a minimum, we have the result shown in Table XVIII. The regular increase in the equatorial acceleration from the small value given by K_3 to the large value given by lanthanum, and the progressive change in radial displacement from −0.063 Å to +0.028 Å between the two levels, indicate, however, that the change in the angular velocity with latitude increases with depth between the upper limits of the chromosphere to a very low level in the reversing layer.

TABLE XVIII

EQUATORIAL ACCELERATION AND DEPTH

	LINE				
	K_3	$H\alpha$	λ 4227	Rev. Layer	*La*
0°−30°	+0°.2	+0°.3	+0°.6	+0°.9	+1°.0
Radial displacement	−0.063	−0.050	−0.002	+0.025	+0.028

The probable arrangement, in order of depth, of the regions effective in producing the phenomena in question is indicated in Table XVI from left to right, in so far as it can be determined from the available observational data. In its general outlines it may be considered to represent our present knowledge of the actual conditions in the solar atmosphere. That we are dealing with different levels seems clear, but the determination of the relative levels in some cases is as yet uncertain.

5. *Magnetic field and level.*—From the point of view that the line displacements due to motion radial to the axis of a spot vortex are criteria for determining the levels at which the spot lines are

[1] *Astrophysical Journal*, 3, 247, 1896.

produced, it is of interest to obtain the field strengths at the levels indicated by the lines for which the separations are known in spot spectra and in the laboratory. In "A Summary of the Results of a Study of the Mount Wilson Photographs of Sun-Spot Spectra,"[1] Mr. Adams gives a list of lines for which the separations in the spot spectra have been measured by Miss Burwell, Miss Wickham, and

TABLE XIX

LABORATORY AND SPOT SEPARATIONS

λ	Element	Intensity	Group	Character Spark	Spark		Spot	
					$\Delta\lambda$	Field	$\Delta\lambda$	Field
5112.996.....	*Cr*	0	..	....	0.947	20,000	0.146	3080
5781.400.....	*Cr*	0	..	Triplet	1.090	20,000	0.125	2300
5783.288.....	*Cr*	2	..	Triplet	1.099	20,000	0.136	2470
5784.080.....	*Cr*	3	..	Triplet	1.080	20,000	0.110	2040
5785.188.....	*Cr*	2	..	Triplet	1.048	20,000	0.137	2610
5903.555.....	*Ti*	00	..	Triplet	0.876	17,500	0.118	2360
5938.035.....	*Ti*	000	..	Sextuplet	0.840	17,500	0.102	2125
5941.985.....	*Ti*	00	..	Sextuplet	0.905	17,500	0.137	2440
6064.853.....	*Ti*	00	..	Triplet	1.159	17,500	0.160	2410
6137.915.....	*Fe*	7	*b*	Triplet	0.654	16,000	0.100	2450
6189.594.....	*Va*	0000	..	Triplet	0.719	20,000	0.117	3210
6200.527.....	*Fe*	6	*b*	Sextuplet?	1.026	16,000	0.098	1530
6213.644.....	*Fe*	6	*b*	Sextuplet	1.200	16,000	0.136	1810
6219.494.....	*Fe*	6	*b*	Sextuplet?	0.991	16,000	0.096	1550
6233.408.....	*Va*	000	..	Triplet	1.048	20,000	0.109	2080
6266.550.....	*Va*	000	..	Triplet	1.688	20,000	0.175	2075
6301.718.....	*Fe*	7	*d*	Sextuplet?	1.063	16,000	0.119	1790
6303.985.....	*Ti*	000	..	Octuplet ?	0.565	17,500	0.093	2880
6312.456.....	*Ti*	00	..	Octuplet ?	0.766	17,500	0.091	2080
6331.067.....	*Fe*	2	*b*	Sextuplet?	0.820	16,000	0.149	2930
6337.048.....	*Fe*	7	*d*	Sextuplet	1.293	16,000	0.151	1860
6344.371.....	*Fe*	4	*b*	Sextuplet?	0.771	16,000	0.091	1890
6400.217.....	*Fe*	8	*d*	Sextuplet?	0.802	16,000	0.086	1720
6411.865.....	*Fe*	7	*d*	Sextuplet?	0.686	16,000	0.086	2000
6531.617.....	*Va*	000	..	Triplet	1.262	20,000	0.161	2550

himself. In using these for the present purpose only the lines that were measured as doublets in the spot spectra have been taken. These are given in Table XIX with the related data. The laboratory separations for iron and titanium are from Mr. King's paper;[2]

[1] *Contributions from the Mount Wilson Solar Observatory*, No. 40; *Astrophysical Journal*, **30**, 124, 1909.

[2] *Contributions from the Mount Wilson Solar Observatory*, No. 56; *Astrophysical Journal*, **34**, 225, 1911.

for vanadium from Mr. Babcock's paper on the Zeeman effect for vanadium;[1] and for chromium Mr. Babcock has kindly supplied the data, partly from his as yet unpublished results. The plate numbers are T 102, T 105, and T 154, and the Greenwich spot numbers are 6393, 6441, 6511, and 6577.

The results for the separate elements arranged in order of line-intensity are given in Table XX.

TABLE XX

MAGNETIC FIELD AND LINE INTENSITY

Element	Intensity									
	0000	000	00	0	2	3	4	6	7	8
Va ..	3210 (1)	2310 (2)	2080 (1)	.....	.....	.....	.....	.....	.....	.....
Cr ..	.....	.....	.....	2690 (2)	2540 (2)	2040 (1)	.....	.....	.....	.....
Ti ..	.....	2500 (2)	2320 (4)	.....	.....	.....	.....	.....	.....	.....
Fe ..	.....	.....	.....	.....	*b* 2930 (1)	.....	*b* 1890 (1)	*b* 1630 (3)	*b* 2450 (1)	*d* 1720 (1)
Fe ..	.....	.....	.....	.....	.....	.....	.....	.....	*d* 1893 (3)	.....

TABLE XXI

MAGNETIC FIELD AND LEVEL AS INDICATED BY DISPLACEMENTS

Intensities...... Elements.......	0000–00 *Va, Ti*	0 *Ti, Cr*	2–4 *Cr, Fe*	6–7 *Fe*	8–9 *Fe*
Field strength	3210 (1) 2310 (2) 2080 (1) 2500 (2)	2690 (2) 2320 (4)	2540 (2) 2040 (1) 2930 (1) 1890 (1)	1630 (3) 2450 (1)	1883 (3) 1720 (1) ....
Means	2485 (6)	2443 (6)	2388 (5)	1835 (4)	1842 (4)
Radial displacements	+0.034	+0.030	+0.023	+0.014	+0.006

With the exception of some irregularities in the case of iron, all four elements show decreasing field strength with increasing intensity of the lines. In forming the final means in Table XXI the values were weighted according to the number of lines of each intensity. The figures in parentheses give the number of lines.

[1] *Contributions from the Mount Wilson Solar Observatory*, No. 55; *Astrophysical Journal*, 34, 209, 1911.

The intensities are grouped so that approximately equal weights may be assigned to each mean, and the titanium lines and the *d* lines of iron, which are at higher elevations than lines of like intensities of vanadium, chromium, and the lines of iron belonging to group *b*, are grouped with lines of the same approximate level.

As is seen by comparison with the chart (Fig. 1), the field strength near the lowest level of the reversing layer is 2485 gausses; and at the level of *Fe* lines of intensity 6–9, it is approximately 1838 gausses, which points to a low gradient along the axis of the vortex. The summary also shows a direct relation between field-strength and radial displacement.

6. *Anomalous dispersion.*—The bearing of the data obtained in this investigation upon anomalous dispersion in reference to solar phenomena is of interest, as radial displacements have been explained by Julius as a consequence of anomalous dispersion in the solar atmosphere.[1] In the figure given to illustrate the way anomalous dispersion acts in producing the shifts of the lines found in the Evershed effect, the red edges of the lines on the peripheral border of the penumbrae are broadened by a rapidly decreasing shading, while the violet border is sharp and the effect decreases from the inner edge of the penumbra outward. This does not represent the conditions found on the plates taken for this investigation, as upon these plates the lines appear to be shifted bodily and are equally sharp on the two edges, and the maximum displacement is at or near the outer border of the penumbra.

Three facts in particular, shown by the data given in this paper, require explanation from the point of view of anomalous dispersion: (1) the variation of displacement with wave-length, which is not a direct result of anomalous dispersion; (2) the systematic variation of displacement with the intensities of the lines; (3) the displacements of lines of the same element in opposite directions, as in the cases of *Ca*, *Na*, *Mg*, *Fe*, *Sr*, which seem to present great and apparently insuperable difficulties for the anomalous dispersion theory.

In a paper on the displacement of the spectrum lines at the sun's limb, Mr. Adams compared the laboratory results on anomalous dispersion with the displacements at the limb, and found no

[1] *Physikalische Zeitschrift*, 11, 65, 1910.

clear relationship between the two phenomena.[1] In commenting upon this Julius says:

That a simple comparison of Geisler's observations on anomalous dispersion of metallic vapors in the arc with displacements at the limb—as given by Adams on page 28—could not possibly serve the purpose of finding such a relationship is evident. . . . . A peculiar feature of our explanation is that both very strong and very weak anomalous dispersion make the displacements small, whereas intermediate values give larger displacements.[2]

In view of the consideration that the basis of all astrophysical investigations rests upon the fundamental postulate that direct comparison is possible between the spectrum results obtained from terrestrial sources and the behavior of the spectrum lines in solar and stellar spectra, the first statement in the quotation is somewhat remarkable. It is difficult to devise a quantitative test of the theory of anomalous dispersion as applied to the sun; the above deduction from the theory, however, can be so used in comparison with laboratory results. It is postulated by the theory that weak and strong anomalous dispersion is associated with small solar displacements. Using as a basis Geisler's tables for anomalous dispersion, the comparison between lines common to his tables and to this paper shows the following:

TABLE XXII

Displacements and Anomalous Dispersion

Lines Common to Both Lists	Anomalous Dispersion	Required by Theory	Observed
5 *Ca* lines, intensity 3–4	Very weak	Small	+0.019Å
2 *Mn* lines, intensity 3	?	Small	+0.028
3 *Cr* lines, intensity 2–3	Very weak	Small	+0.033
3 *Zn* lines, intensity 1–3	Very weak	Small	+0.032
2 *Ni* lines, intensity 3–4	?	Small	+0.030
1 *Sr* line, intensity 1	Very strong	Small	+0.030
2 *Al* lines, intensity 15–20	Moderate	Large	+0.001
2 *Fe* lines, intensity 15	Weak	Small	−0.005
2 *Na* lines, D_1 and D_2 20–30	Very Strong	Small	−0.006
2 *Mg* lines, intensity 20–30	{Weak / Very weak}	Small	−0.011
2 *Ca* lines, H and K	Strong	Small	−0.063
4 *Fe* lines, intensity 8–20	{Weak / Very weak}	Small	−0.003

Mean radial displacement for intensities 1 to 10 = 0.016 Å.

[1] *Contributions from the Mount Wilson Solar Observatory*, No. 43, 28; *Astrophysical Journal*, 31, 57, 1910.

[2] *Astrophysical Journal*, 31, 428, 1910.

In general, lines of weak intensity show small anomalous dispersion, and according to the above statement should give small displacements, but the measurements given in this paper show quite the reverse. The 16 lines of mean intensity 3 in the upper part of the table give a mean displacement of 0.027 Å, which is a large value, as may be seen from the mean (0.016 Å) of lines from intensities 1 to 10. There is one striking exception to the general rule that weak lines show small anomalous dispersion, and that is *Sr* λ 4607, which exhibits very strong anomalous dispersion, but gives, contrary to the theory, a very large displacement. The two aluminum lines show a moderate degree of anomalous dispersion, and, according to Julius, such lines should give large displacements in the sun; the value, however, is 0.001 Å. The two lines of iron of intensity 15 and the magnesium lines b_1 and b_2 show weak and very weak anomalous dispersion, the D_1 and D_2 lines of sodium and the H and K lines of calcium a larger amount. In these four cases the above deduction from the anomalous dispersion theory requires small positive solar displacements. The actual values are −0.005, −0.006, −0.011, and −0.063 Å, opposite in direction to the demands of the theory. The four lines of iron of intensity 8 to 20 show weak and very weak anomalous dispersion and small displacement, and are the four lines out of the thirty whose displacements are not opposed to the deduction from the theory; but they are moderately high-level lines and should show small radial displacements.

In the paper by Julius to which reference has been made he remarks:

> That the lines of the elements of very high atomic weight, such as lanthanum and cerium, show very small displacements [at the sun's limb] is easily accounted for if we assume their vapors to be extremely rare in the solar atmosphere. This explanation is certainly not less simple than the one proposed by Adams on pp. 17 and 18 of his paper, where he has to find a way out of the discrepancy to which in that case the pressure hypothesis appears to lead.

It is of interest in view of this explanation, from the point of view of anomalous dispersion, to note that the displacements of the lanthanum and cerium lines in the edges of the penumbrae of eccentrically located spots are very large, larger, in fact, than for

the lines of any other element except lead (at. wt. 207), ytterbium (at. wt. 173), and niobium (at. wt. 94), from which it is evident that vapors of the elements that occur in small quantities in the solar atmosphere give the largest radial displacements. If the displacements at the limb and in spot penumbrae are due to anomalous dispersion, it is somewhat difficult to reconcile the very small displacements of the lines of these elements in one case with the very large displacements of the same elements in the other. And if the effects due to anomalous dispersion are small in the case of lanthanum and cerium because of the rarity of these vapors in the solar atmosphere, the relatively great brightness of the weak solar lines of these elements in the flash spectra of Mitchell and Campbell seems difficult of explanation from the point of view of anomalous dispersion.

According to the dispersion theory there is no displacement or bending of the lines by refraction when the slit of the spectrograph is perpendicular to the radius of the solar disk passing through the center of the umbra. After speaking of the effect when the slit is parallel to the radius, Julius says:[1] "Bei jeder anderen Richtung des Spaltes muss der Effekt geringer sein; er verschwindet, wenn der Spalt den Fleck in einer Richtung senkrecht zu einer Verbindungslinie zwischen dem Fleck und dem Mittelpunkte halbiert." Displacements of the H and K line are observed, but much less frequently, with the slit perpendicular than with it parallel to the radius. The parallel position often shows displacements when, on exposures taken on the same plate and the same spot with the perpendicular position, no displacement is observable. Both displacements are very simply explained as Doppler effects, indicating an inflow into practically all spots and occasionally a cyclonic movement of the high-level vapor in the case of particularly strong and regular spots.

In the case of the winged lines, the anomalous dispersion theory considers that the core of the line is a pure absorption effect. Of H_β Professor Julius says:[2] "Die schmale mittlere Linie nun ist die wahre Absorptionslinie H_β, die natürlich durch Brechung nicht

[1] *Physikalische Zeitschrift*, 11, 65, 1910.

[2] *Ibid.*, p. 66.

verschoben oder gekrümmt werden kann." The measurements upon the strong winged lines are of necessity made upon the central portion, the hard and sharp core. The plates taken in the course of this investigation for determining the displacements of the winged lines of *Fe*, *Na*, *Mg*, *Al*, *H*, and *Ca* were so strongly exposed and developed that the wings were obliterated and the measurements were made upon what the anomalous dispersion theory considers are true absorption lines, so that the displacements in the case of these lines would seem to be free from effects due to that cause.

The relative displacements of the lines of the reversing layer at the east limb and west limb of the sun have never been attributed to anomalous dispersion. The agreement between the levels shown by rotation results and radial displacements would tend to show that the radial displacements are independent of anomalous dispersion, and represent probably a Doppler effect.

The effects due to anomalous dispersion in certain laboratory experiments are so striking that, from the point of view of the physicist, it has seemed improbable that they would be generally absent from solar phenomena. The absence of displacements of solar lines that may with certainty be ascribed to anomalous dispersion has been attributed generally to the small quantity of vapor of any one element in the solar atmosphere. But as has been shown for calcium, the quantity above the level of lines of intensity unity is probably equivalent to a column some sixty-seven meters long at 3000° C., and under a pressure of one atmosphere. This is a far greater quantity than is necessary to produce the marked anomalous dispersion shown by the H and K lines in laboratory experiments. In a paper "On the Application of the Laws of Refraction in Interpreting Solar Phenomena,"[1] Mr. Anderson compares the conditions in the sun with the conditions under which anomalous dispersion is obtained in the laboratory. The photosphere subtends over the general disk practically an angle of 180° at any point in the solar atmosphere—reversing layer or chromosphere—and may be considered an infinite, plane, self-luminous surface. Such a surface, he shows, would appear uniformly lumi-

[1] *Astrophysical Journal*, 31, 166, 1910.

nous even if covered by an atmosphere full of *Schlieren*, provided the deviation does not exceed 90°. He shows further that in the case of solar phenomena the angles of deviation are small, and that the absorption bands would have exactly the same width and character as they would have if produced by a perfectly homogeneous atmosphere of the same absorptive power. It seems probable that observable effects due to anomalous dispersion in the solar atmosphere are exceptional, and that until we are able to depend upon measurements of solar wave-lengths to the fourth decimal place, at least, its contribution to the relative positions of the Fraunhofer lines, if any, will be masked by phenomena due to other causes.

7. *Solar and terrestrial analogies.*—The percentage composition of the terrestrial atmosphere does not change appreciably within 15 km above the earth's surface, owing to the mixing process kept up by storms and convection currents. Above that level the density of the heavier gases decreases more rapidly than that of the lighter gases, so that with increasing elevation the lighter gases gain in percentage, though decreasing in absolute density, until at 100 km hydrogen forms 99.5 per cent and helium 0.5 per cent of the atmosphere.[1] The march of conditions in the regions of the solar atmosphere accessible to observation appears to be very like that in the terrestrial atmosphere, the lighter constituents gaining in percentage over the heavier ones at higher levels. The slope of an imaginary line drawn through the highest levels given in the chart (Fig. 1) is probably too great, because of the lack of strong lines given by the heavier elements; but if we should grant to all elements lines of equal intensity in the solar spectrum, it would still follow that the heavier elements are at the lower levels. For if we place at the extreme right the element whose lines actually present in the solar spectrum originate the farthest below iron lines of the same intensity, and precede it by the elements whose lines determined by reference to the same iron scale originate at successively higher levels, the last eight in the series will be: *Nd* 144, *Ba* 137, *La* 138, *Pb* 207, *Cd* 112, *Yb* 173, *Nb* 94, *Ce* 142. These are the eight heaviest elements in the list, having an average atomic

[1] Hann, *Lehrbuch der Meteorologie*, p. 8, 1906.

weight of 143 against an average of 49 for the other 19 elements considered.

In the terrestrial atmosphere below 3 km there is a turbulent stratum, the region of storms and powerful convection currents and irregular temperature gradients. Above this stratum and below 10 km is the region of comparatively uniform changes where the normal condition is one of stability, though during storms it may be the seat of vertical convection currents. Lastly is the outer relatively quiescent stratum, the region of a uniform or inverted temperature gradient, intermingling but slightly with the underlying levels. The division between the two lower layers is less pronounced than that between them considered as one region and the outer layer.[1]

In the lower solar atmosphere, the region including the lowest levels of the reversing layer, and especially the underlying gases, is the region of tremendous disturbances in which the upper portion of the sun-spot vortex is located, in which occurs the outflow of material from the interior of the sun, and where more or less mixing must occur. Above this turbulent region, yet more or less involved in its activities, is the general reversing layer, whose normal condition seems to be one approaching more nearly a stable state. The chromosphere seems quite sharply distinguished from this region both in its composition and in the movements of its constituent gases near spots. The separation appears to be at the level of zero tangential velocity, or the level of velocity-inversion in the case of the flow radial to the axis of the solar vortex. In the case of terrestrial cyclonic storms, but little is known from direct observation of the atmospheric movements over the center of the storm, while, in the case of storms in the solar atmosphere, the point of observation is from the outside and the upper movements are those directly detected. It would be interesting if our knowledge of terrestrial cyclonic storms should be supplemented by solar observations.

Though the general circulation of the two atmospheres may have little in common, it seems quite probable that cyclonic storms, whatever their determining causes, will follow the same hydro-

[1] Moore, *Descriptive Meteorology*, p. 119, 1910.

dynamical laws, and that observations in regions so widely separated as the sun and earth may be combined in studying the complete cyclonic system.

There is nothing in the deductions from the observations that suggests a stratification of the solar atmosphere. If, for the present, we leave helium and the coronal material aside, and confine the considerations to the elements included in this investigation, the indicated distribution is easily imagined. As one penetrates this atmosphere from without the sun, he would first encounter an atmosphere due to "that form of calcium vapor that produces the H and K lines"; to this is successively added hydrogen and the vapors of magnesium, sodium, iron, aluminum, etc., each increasing in absolute density with the depth until in the lowest portion of the reversing layer occur also the vapors of all the elements whose lines appear in the solar spectrum.

GENERAL CONCLUSIONS

1. The differing displacements shown by the Fraunhofer lines at the peripheral edges of the penumbrae of eccentrically located sun-spots seem to find their simplest explanation in movements of the solar vapors tangential to the solar surface with velocities varying with the elevation.

2. Assuming as a standard the series of displacements shown by the *Fe* lines, which decrease regularly from +0.034 Å for intensity 00 to +0.004 Å for intensity 10, the relative levels of the lines of 26 other elements of the reversing layer and chromosphere have been determined and plotted in a chart of distribution.

3. The resulting distribution shows that the H_3 and K_3 lines of calcium are the lines of highest level, followed by the H_α line of hydrogen, and that, in the main the heavy and rare elements occur in detectible amounts only in the lower portions of the solar atmosphere.

4. The enhanced lines show smaller radial displacements than unenhanced lines of the same solar intensities and would appear to originate at higher levels in and near sun-spots.

5. The *Fe* lines of groups *d*, *sub-d*, and *e* show smaller displacements than those of group *b* and are assigned a higher level.

6. The quantities of absorbing vapors in the solar atmosphere seem sufficient to produce in general complete absorption.

7. Large positive radial displacements are associated with low heights above the photosphere and large negative displacements with great heights, when a comparison is made between radial displacements and elevation deduced from eclipse results.

8. The mean radial displacement of lines of the reversing layer occurring frequently in flash spectra is +0.009 Å; of those observed less frequently it is +0.023 Å.

9. A comparison of the radial displacements with the weakening and strengthening of spot lines shows that strengthening increases with depth, and that weakening is associated with high elevations.

10. A discussion of the displacements between the center and limb of the sun from the point of view of levels as indicated by radial displacements leads to the conclusion that pressure plays the predominating rôle in the phenomenon, but that the effect is modified by the scattering of light in the lowest levels and by the downward movement of the high-level vapors.

11. When the Mount Wilson rotation results are compared in detail with the corresponding radial displacements, a remarkable agreement is found. Low values for solar rotation are associated with large positive radial displacements, and high values for rotation with large negative radial displacements. The data in both cases place the level of the lanthanum lines below, and the level of the hydrogen lines above, the mean level of the reversing layer.

12. When the strength of the magnetic field in sun-spots is calculated from the separations in spot spectra and the laboratory separations of the same lines in known magnetic fields, widely different values are obtained, but when the lines are assigned to the relative levels indicated by their radial displacements the field strength decreases consistently with elevation.

13. According to the theory of anomalous dispersion, both very weak and very strong anomalous dispersion makes the displacements of the Fraunhofer lines small, whereas intermediate values give larger displacements; and in the case of the winged lines the core is the true absorption line and is not displaced by refraction.

Judged by these criteria radial displacements in the penumbrae of sun-spots are not due to anomalous dispersion as none of the above criteria is satisfied.

14. The displacements of the Fraunhofer lines in the penumbrae of sun-spots give a means of sounding the solar atmosphere and of assigning relative levels to the sources of the lines. Aside from the inherent probability of the interpretation, it is confirmed by eclipse results and is in harmony with a wide range of solar observations, and opens the way to further solar research.

Mount Wilson Solar Observatory
May 31, 1913

THE NON-SELECTIVE TRANSMISSIBILITY OF RADIATION THROUGH DRY AND MOIST AIR

By F. E. FOWLE[1]

Determinations of the non-selective absorption of radiation between the wave-lengths $0.34\,\mu$ and $1.7\,\mu$ associated with atmospheric aqueous vapor and of the general transmission coefficients for radiation passing through a dry atmosphere are here given. The observations used were made during two years when the atmosphere was of exceptional purity relative to foreign particles, such, for instance, as volcanic dust.

METHOD AND DATA

Briefly, the procedure consists in correlating the atmospheric scattering of solar radiation with the amount of water-vapor present. In an earlier paper[2] were given the determinations of the amount of aqueous vapor above Mount Wilson, stated as so much precipitable water, for some 180 days of the years 1910 and 1911. This amount of water-vapor was found by means of the depths of certain bands produced by it in the infra-red spectrum, under standard spectroscopic conditions, as discussed in a yet earlier communication.[3] On most of these days, the transmissibility of radiation through the air above Mount Wilson was available from the regular determinations of the solar constant of radiation. It was computed at 23 wave-lengths in 1910, 33 in 1911, within the above-mentioned wave-length interval.

The transmissibility at any wave-length varies from day to day, depending, it may be supposed, on the amount both of dust and of aqueous vapor present. The days of observation were divided into groups according to the amount of aqueous vapor present. At each wave-length a mean coefficient of transmissibility for each group was obtained. This for a given wave-length may be considered as made of two parts, one $a_{w\lambda}$ depending upon the water-vapor and

[1] Published by permission of the Secretary of the Smithsonian Institution.

[2] *Astrophysical Journal*, **37**, 359, 1913. [3] *Ibid.*, **35**, 149, 1912.

variable from group to group; the other, $a_{a\lambda}$ which, were the observations numerous enough, might be considered as constant and due to dry air of average transparency. It is here assumed that the dates included in each group were distributed sufficiently at random.

The units were so chosen that $a_{a\lambda}$ is the mean vertical atmospheric transmissibility above Mount Wilson of radiation through dry air at the wave-length λ, and $a_{w\lambda}$ the corresponding factor of change of transmissibility when there is 1 cm of "precipitable" water in the form of vapor distributed in a vertical column of the atmosphere. Then if w is the depth in centimeters of the precipitable water in the atmosphere and a_λ the corresponding transmissibility,

$$a_\lambda = a_{a\lambda} a_{w\lambda}^{w}$$

or, taking logarithms,

$$\log a_\lambda = \log a_{a\lambda} + w \log a_{w\lambda} .$$

Hence if the observations are plotted with the two quantities derived from the observations as co-ordinates, that is, with log a_λ as ordinates and w as abscissae and the best representative right line drawn, the tangent of its inclination to the axis of abscissae will be log $a_{w\lambda}$, the logarithm of the coefficient of transmissibility of radiation, associated with atmospheric water-vapor (1 cm precipitable water) and the intercept on the axis of ordinates will be log $a_{a\lambda}$, the logarithm of the coefficient of transmissibility through dry air.

In Fig. 1 are shown the plots of the group-means for five different wave-lengths and the representative right lines used. Each group into which the data were collected is represented by a point and, except that for the greatest amount of vapor, depends on the observations for ten dates. Each line depends upon some 180 observations except those for the ten wave-lengths for which 1911 data alone were available. In Table I is given a sample set of data. The divergencies of the various points from the representative lines are an indication that the ten observations do not give chance the opportunity to produce a sufficiently representative mean, rather than that there is not a very definite correlation between aqueous vapor and the coefficients of transmissibility. Both abscissae and

ordinates of the data of the wettest days have less weight. It was thought best to plot and reduce each year separately. The results were then weighted according to their grades so that 1911 usually

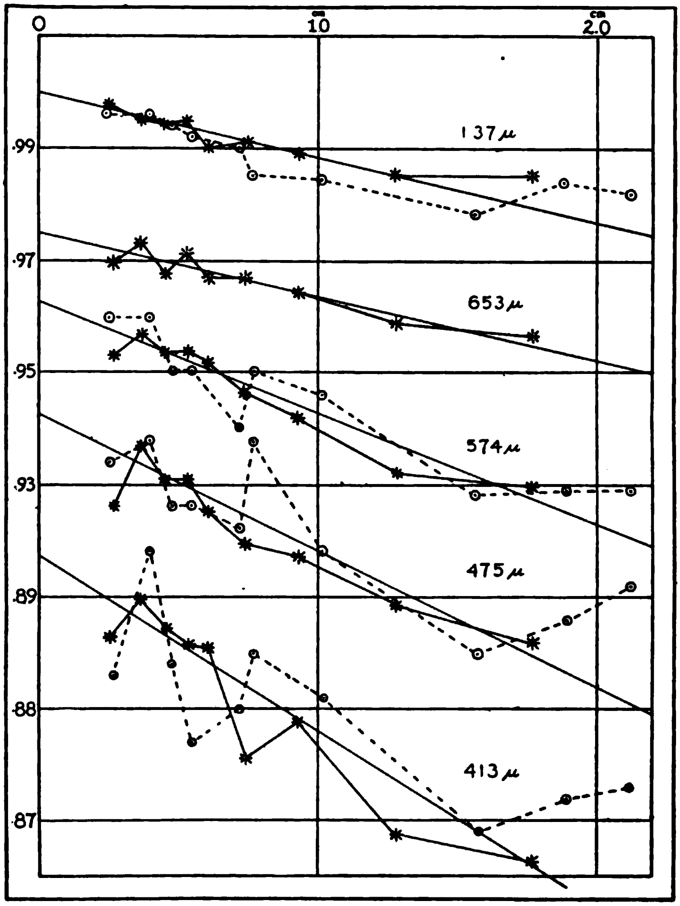


FIG. 1.—Transmissibility of radiation through moist air above Mount Wilson. Ordinates are logarithms of transmissibilities. Abscissae are centimeters of precipitable water in vertical column of atmosphere.

had double weight because improved reduction methods rendered its transmissibility coefficients for radiation through air more reliable. The resulting coefficients for water-vapor throughout the

spectrum agree for the two years within three- or four-tenths of 1 per cent. The resulting values for $a_{w\lambda}$ and $a_{a\lambda}$ are shown in Fig. 2.

TABLE I

ATMOSPHERIC TRANSMISSIBILITY COEFFICIENTS AT 0.384 μ AS DEPENDENT UPON AQUEOUS VAPOR, 1911

Precipitable Water

Means	cm 0.268	cm 0.364	cm 0.454	cm 0.535	cm 0.603	cm 0.746	cm 0.929	cm 1.279	cm 1.768
	0.667	0.692	0.708	0.676	0.650	0.711	0.718	*0.664*	.....
	.745	.690	.686	.703	.697	.698	.702	*.665*	.....
	.684	.715	.687	.652	.718	.615	.673	.655	.....
	.708	.695	.723	.718	.724	.670	.655	.596	.....
	.681	.686	.705	.682	.698	.686	.673	.692	.....
	.692	.692	.679	.718	.714	.678	.686	.695	*0.700*
	.706	.719	.681	.665	.687	.706	.664	.697	*.700*
	.702	.656	.711	.681	.700	.706	.666	*.700*	*.604*
	.698	.714	.708	.711	.653	.692	*.664*	*.700*	*.662*
	0.686	0.682	0.695	0.697	0.653	0.698	*0.665*	*0.662*	0.650
Means..	0.6976	0.6941	0.6983	0.6903	0.6894	0.6860	0.6766	0.6726	0.6632

The values in italics were used in two groups.

TRANSMISSIBILITY OF RADIATION THROUGH DRY AIR

The upper curve *a* of Fig. 2 represents the transmissibility of radiation through the dry air vertically above Mount Wilson (altitude 1730 m), at a period when the air was exceptionally free from volcanic matter. The transmission ranges from 0.684 at the wave-length 0.3709 μ to 0.992 at 1.73 μ. The values for wave-lengths shorter than 0.3709 μ are of doubtful worth, the increased transmissibility being very probably an effect of the field light in the spectroscope. There is a depression in the curve from about wave-length 0.5026 μ to 0.7644 μ probably due to selective absorption in the permanent gases of the earth's atmosphere. A table is inserted in the plot indicating at the proper places all the atmospheric lines included in Rowland's "A Preliminary Table of Solar-Spectrum Wave-Lengths,"[1] which extends from 0.297 μ to 0.733 μ. Rowland gives more than 440 atmospheric lines in this region between 0.5026 μ and 0.7644 μ besides those due to water-vapor.

[1] *Astrophysical Journal*, 1895–1897.

The dotted line above this region will be explained later. It is supposed to represent the transmissibility in this spectral region were it entirely non-selective (molecularly scattered?).

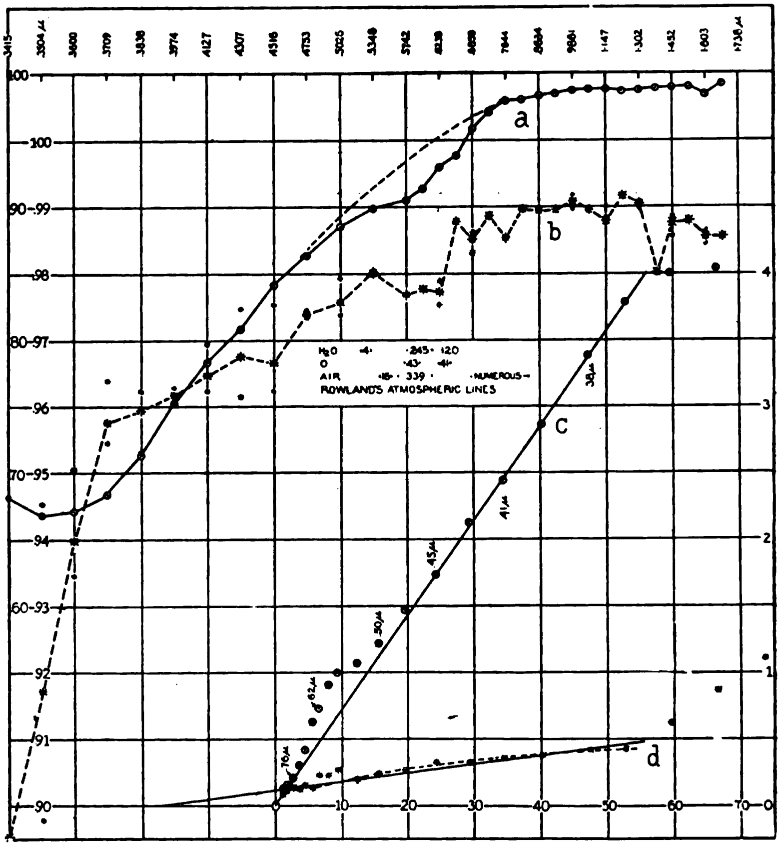


FIG. 2.—Curve *a*) Transmissibility of radiation through dry air vertically above Mount Wilson, 1910–1911. ($a_{a\lambda}$)

b) Factor of change produced by atmospheric aqueous vapor (1 cm precipitable water). ($a_{w\lambda}$)
Ordinates for *a* and *b*: transmissibilities;
Abscissae for *a* and *b*: deviations ultra-violet glass prism.
The corresponding wave-lengths are inserted at the top.

c) Ordinates, values of C, where $a_{a\lambda}=e^{-C}$ (dry air);
Abscissae, $\lambda^{-4}\times 10^{-16}$.

d) Ordinates, values of C, where $a_{w\lambda}=e^{-C}$ (water vapor);
Abscissae, $\lambda^{-4}\times 10^{-16}$.

In the region of wave-lengths shorter than $0.5\ \mu$ Rowland does not give a single atmospheric line. There may be a few. Cornu,[1] observing with a quartz spectroscope set at $0.423\ \mu$, examined the spectrum of the electric lights on Eiffel Tower 4350 m away (=0.54 atmosphere) and observed no telluric lines at this end of the spectrum even though the evening was rainy. His observations were limited at $0.329\ \mu$ by the glass lens over the tower light. He gives as the tension of the water-vapor in the air 8.6 mm, which corresponds to about 4 cm precipitable water in the path of his beam.

The great oxygen bands at *A* and *B* were eliminated in the present study by drawing a smooth curve over their tops in the bolographs and making on that curve the measures in the corresponding parts of the spectrum in order to measure only the non-selective absorption.

TRANSMISSIBILITY OF RADIATION THROUGH ATMOSPHERIC WATER-VAPOR

The dotted curve *b* of Fig. 2 gives the factor of change in the transmissibility of radiation through air when it contains 1 cm precipitable water in the form of vapor as it actually exists in a vertical column through the atmosphere. It ranges from 0.957 at the wave-length $0.37\ \mu$ to 0.99 in the infra-red. The depression between $0.535\ \mu$ and $0.650\ \mu$ is due to the selective absorption of some fine aqueous vapor lines. Because of the non-homogeneity of the radiation the transmission coefficients are doubtless somewhat too great in this region. The great water-vapor bands a, α, ρ, Φ, Ψ, and Ω and the oxygen bands at *A* and *B* were eliminated by using smoothed bolographs as in the case with dry air.

MOLECULAR SCATTERING OF RADIATION IN AIR

Rayleigh and Schuster have shown that if E_0 is the incident energy, E the energy transmitted through a gas, x the length of path, e the base of the natural logarithms, μ the index of refraction, λ the wave-length, and N the number of molecules per unit of volume, then

$$E = E_0 e^{-kx}$$

where

$$k = \frac{32\pi^3(\mu - 1)^2}{3N\lambda^4} .$$

[1] *Astrophysical Journal*, 13, 142, 1901.

L. V. King has quite recently further elaborated this analysis and used it[1] in the discussion of the Smithsonian measures.[2] He derives the following expression:

$$C_x = \frac{32}{3}\left\{\pi^3(n_0-1)^2\frac{H}{N_0}\lambda^{-4}+a_0H\right\}\frac{p}{p_0}+(\text{term due to dust}),$$

where C_x corresponds to the k of the previous equation taken at the altitude x where the atmospheric pressure is p, p_0 the corresponding pressure at sea-level, H the height of a homogeneous atmosphere at 760 mm, 0° C., N_0 the number of molecules in a cubic centimeter at the same standard pressure and atmosphere, a_0H a term depending on the amount of energy absorbed and converted into heat. This equation is of the form $y=mx^{-4}+b$.

Through the relation $a_{a\lambda}=e^{-C_x}$, the coefficients of the earlier part of this communication were properly transformed and the results plotted in the lower right-hand part of Fig. 2. The steeper plot, c (circles), relates to air, the other, d (crosses), to water-vapor. The values of C_x were used as ordinates, $\lambda^{-4}\times 10^{-16}$, as abscissae. It seemed apparent that the right line best representing the points should pass through the zero of co-ordinates, making the last two terms of the equation for C_x zero. The points between the wave-lengths 0.503 μ and 0.764 μ lie in a region where strong selective absorption exists and therefore should not be taken into account. The value of the tangent m for this line was measured as 0.724×10^{-18}, whence

$$N_0 = \frac{32}{3}\pi^3(n_0-1)^2\frac{Hp}{mp_0}$$

$$=(10.7)(31.0)(8.58\times 10^{-8})\frac{7.99\times 10^5 620}{.724\times 10^{-18} 760}$$

$$=2.56\times 10^{19}$$

[1] *Philosophical Transactions of the Royal Society of London*, A **212**, 375, 1913. Schuster earlier discussed the matter and concluded that molecular scattering practically wholly accounts for the light scattered, although the data then available were far less adapted to the discussion than that of the present research (*Nature*, **81**, 97, 1909). Mention should also be made of the treatment of the matter on the electron theory by Natanson ("On the Theory of Extinction in Gaseous Bodies," Cracovie Académie des sciences, *Bulletin internationale math. et phys.*, p. 915, 1909).

[2] Abbot, Fowle, and Aldrich, *Annals of the Astrophysical Observatory of the Smithsonian Institution*, Vols. 2 and 3.

which corresponds very closely to the value 27.1 billion-billion, probably the best value at present from other methods for the determination of the number of molecules per cc at 760 mm, 0° C. (Millikan). This indicates that over a considerable portion of the spectrum the depletion of energy from the direct beam from the sun or other celestial body is due to molecular scattering. Also that during these two years, 1910 and 1911, the average transparency of the sky above Mount Wilson was little affected by dust. What little dust there may have been would have tended to make the above value for N_0 too small.

A significant point is that this correspondence between theory and observation is a confirmation of the correct estimation of the atmospheric losses in the Smithsonian determinations of the solar constant of radiation.[1] This confirmation does not hold, however, in the region of selective absorption between 0.503 μ and 0.764 μ. Here the spectrum probably consists of regions of normal molecular scattering separated by narrow lines of selective absorption. Theoretically the observed transmission coefficients must be somewhat too great in this region. Certainly the molecular scattering even here predominates, because not only are most of the atmospheric lines very faint, especially above Mount Wilson, but the extent of spectrum they cover is small, as may be judged by their fewness compared to the number of solar lines in the same region. There were noted at sea-level by Rowland 3500 solar lines and 440 atmospheric lines. The intervening spaces between the lines count on the side of molecular scattering. Across the top of this selective-absorption band has been drawn in the upper curve *a* of Fig. 2 a dotted line computed from the corresponding points of the right line of the lower *air* plot and this represents the theoretical values for this region on the assumption of non-selective scattering.

THE SCATTERING ASSOCIATED WITH ATMOSPHERIC WATER-VAPOR

It is of interest to apply the same method of analysis in the estimation of the number of molecules corresponding to the depletion of radiation connected with atmospheric water-vapor. If N_{w}

[1] *Annals of the Astrophysical Observatory of the Smithsonian Institution*, Vols. 2 and 3.

be the molecules in a cubic centimeter at the temperature t and the pressure p, the density of aqueous vapor approximately[1]

$$\frac{0.81p\times 10^{-3}}{(1+at)760}$$

which equals the weight in grams per cc, in other words the reciprocal of the height of a column 1 cm square, containing 1 cm precipitable water at the temperature t and the pressure p, then, taking 0.67×10^{-19} as the tangent of the representative line for the water-vapor data in the lower part of Fig. 2,

$$N_{tp}=\frac{32\pi^3}{3}\left\{\frac{(.000261)p}{(1+at)760}\right\}^2\left\{\frac{(1+at)760\times 10^3}{(0.81)p}\right\}\frac{1}{0.67\times 10^{-19}}$$
$$=(4.17)(10^{17})\left\{\frac{p}{(1+at)760}\right\}.$$

But assuming that Avogadro's law applies in this case of water-vapor, the number of molecules which would be expected is

$$N_{tp}=(2.7)(10^{19})\left\{\frac{p}{(1+at)760}\right\}$$

or about 64 times as many. Thus it is found that the scattering of radiation indicated by the water-vapor data is far greater than would be expected from the number of molecules of water-vapor present.

THE TRANSMISSIBILITY BY LIQUID WATER

Before discussing further the water-vapor results, it will be interesting to consider Table II, which contains some values of C determined by Kreusler[2] for a layer of liquid water 1 cm thick and extending over a considerable range of wave-lengths in the ultra-violet.

The data were plotted with C as ordinates and λ^{-4} as abscissae, and with the exception of the first three measures they lie remarkably well on a right line passing through the zero of co-ordinates. The first three values show greatly increased absorption as they approach a band of great selective absorption at $0.115\ \mu$ (metallic

[1] Jamin, *Annales de chimie et de physique* (3), **62**, 171, 1858, whence is taken also the index of refraction for water-vapor.

[2] *Annalen der Physik*, **6**, 412, 1901.

absorption[1]). In the last line of Table II are given the tangents of the line drawn from each separate point to the origin. The mean value is 1.15×10^{-21}, the tangent of the best representative right line for all the points.

TABLE II

TRANSMISSIBILITY BY LIQUID WATER

λ in μ	0.186	0.193	0.200	0.210	0.220
$\lambda^{-4} \times 10^{-16}$	833.	725.	625.	515.	427.
C	0.0688	0.0165	0.0090	0.0061	0.0057
$m \times 10^{+23}$	....	....	....	118.	134.
λ in μ	0.230	0.240	0.260	0.300	....
$\lambda^{-4} \times 10^{-16}$	357.	301.	219.	123.	....
C	0.0034	0.0032	0.0025	0.0015	....
$m \times 10^{+23}$	95.	106.	114.	122.	....

At yet longer wave-lengths the data determined by Ewan[2] and Aschkinass[3] are available and are given in Table III.

TABLE III

TRANSMISSIBILITY BY LIQUID WATER

λ in μ	0.415	0.430	0.450	0.475	0.487	0.500
$\lambda^{-4} \times 10^{-16}$	33.8	29.2	24.4	19.6	17.8	16.0
C Ewan	0.00035	0.00023	....	....	0.00014	....
C Aschkinass	....	....	0.00020	0.00020	....	0.00020
$m \times 10^{+23}$	104.	79.	82.	102.	79.	125.
C Fowle	0.035	0.032	0.32	0.026	0.025	0.024

The last line gives values for atmospheric water-vapor.

Beyond $0.50\,\mu$ another band of selective absorption is rapidly entered. The mean of the tangents for this set is 0.95×10^{-21}, so that these points lie very close to the line representing the first group.

Now suppose this centimeter-thick layer of liquid water were to have this same transmissibility in vapor form (corresponding to 1 cm precipitable water). Then in place of the tangent 0.67×10^{-19} either 1.15×10^{-21} or 0.95×10^{-21} would be substituted. The values for N_0 would be respectively 2.43×10^{19} and 2.94×10^{19}. The first value is surely too small for the data because the square of

[1] Martens, *Annalen der Physik*, **6**, 603, 1901.

[2] *Proceedings of the Royal Society*, **57**, 117, 1894.

[3] *Annalen der Physik und Chemie*, **55**, 401, 1895.

the index of refraction for water-vapor used applies to wave-lengths near the D lines. If the index varies as much with the wave-length for aqueous vapor as it does for air, then 2.43 should be increased by about 1/9 and becomes 2.70.

This would seem to lead to the conclusion that over this quite great range of wave-lengths, $0.210\,\mu$ to $0.500\,\mu$ (nearly an octave and a half), between the two bands of selective absorption centering at $0.115\,\mu$ and $0.600\,\mu$, the depletion of light in passing through liquid water is due to molecular scattering, and that the molecules of liquid water behave like H_2O in scattering light, not as $(H_2O)_2$, dihydrol, or $(H_2O)_3$, trihydrol. Other properties[1] of water have led to the conclusion that liquid water is a mixture of $(H_2O)_2$ and $(H_2O)_3$, and that ice is $(H_2O)_3$.

ATMOSPHERIC AQUEOUS VAPOR

It is evident then that the radiation losses in passing through atmospheric aqueous vapor are not only much greater than could be accounted for by purely molecular scattering but are also very much greater than would occur in the transmission of rays of wave-lengths between $0.21\,\mu$ and $0.50\,\mu$ through the same quantity of water in the liquid state. This latter fact was unexpected, since at longer wave-lengths liquid water is far less transparent than the equivalent vapor. One cm of liquid water is practically opaque to radiation from $1.2\,\mu$ to $8\,\mu$,[2] while as atmospheric vapor, except in the bands of great selective absorption, it transmits 99 per cent in this spectrum region.

Referring again to *d*, Fig. 2, probably the dotted line drawn more truly fits the data. This indicates a departure from strict proportionality between scattering and λ^{-4}. The departures are in the sense of giving relatively too high observed coefficients ($a_{w\lambda}$) in the violet and absolutely too high ones all through the spectrum as compared with what would be produced by the scattering by water-vapor molecules alone. Such an effect as this departure would result from encounters of the radiation with scattering obstacles of

[1] Röntgen, *Annalen der Physic und Chemie*, **45**, 45, 1892; Sutherland, *Philosophical Magazine* (5), **50**, 460, 1900.

[2] E. F. Nichols, *Physical Review*, **1**, 1, 1893; Coblentz, *Bulletin Bureau of Standards*, **7**, 632, 1911.

a greater order of magnitude than molecules, such for instance as hydrols, nuclei, ions, or dust.[1]

The evidence furnished by liquid water is perhaps against the supposition of hydrols. In deriving the transmissibility coefficients, $a_{w\lambda}$, the assumption was made that there was no correlation between dust and water-vapor. It may be that the dust content of the atmosphere is more or less proportional to the amount of water-vapor, although this seems somewhat improbable. Considerable evidence collected by Aitken[2] in the Alps and elsewhere seems to show no such proportionality. He even states that the greatest amount of dust may be present in the dryest weather.[3]

There remain the nuclei or the ions as a possible explanation of the abnormally great general absorption associated with atmospheric water-vapor. Ions are always present in the air, and if any water-vapor is present it will probably be condensed upon them in small drops which may be of the order of 10^{-7} cm. For a further discussion of ions as centers for the formation of small water particles the reader may be referred to chap. vii of the second edition of J. J. Thomson's *Conductivity of Electricity through Gases*.

Wilson[4] has shown that, under the influence of ultra-violet light, in moist dust-free air nuclei are formed and may grow "till they become large enough to scatter ordinary light." By careful laboratory researches he has shown that oxygen and water-vapor alone are necessary for their production; that water-vapor is necessary; that saturated vapor is not necessary; that they persist for some time after formation; that these nuclei are different from ions since they carry no electric charge; that they are probably due to some combination, H_2O_2, which by decreasing the vapor pressure allows drops of water containing one of them to form and to grow where pure water drops would evaporate. Bieber[5] has since shown that

[1] For instance, compare the effect of volcanic dust in 1912 when Mr. Abbot's observations in Bassour showed transmission coefficients due to the volcanic dust not varying by 1 per cent throughout the visible spectrum (0.36 μ to 0.80 μ), Abbot and Fowle, "Volcanoes and Climate," *Smithsonian Misc. Collections*, **60**, No. 29, 1913.

[2] *Transactions Royal Society of Edinburgh*, **37**, 17.

[3] *Ibid.*, **35**, 1.

[4] *Philosophical Transactions of the Royal Society*, **192**, 403, 1899.

[5] *Annalen der Physik*, **39**, 1313, 1912.

H_2O_2 is formed by the action of ultra-violet light. Although the ultra-violet energy in sunlight is too weak at the surface of the earth to be very efficient in the formation of these nuclei, in the clear air above Mount Wilson it may well be very active. In such nuclei, dependent directly upon the presence of water-vapor, there seems a sufficient explanation of the increased absorption.

Before concluding, the writer wishes to express his gratitude to Mr. Abbot for his criticisms and suggestions in the course of the preparation of this matter for publication.

SUMMARY

The change in the transmissibility of radiation associated with atmospheric water-vapor between the wave-lengths $0.371\ \mu$ and $1.74\ \mu$ has been determined. Thence became possible the evaluation of the transmissibility for dry air vertically above Mount Wilson (1730 m). In the following table are given for a few selected wave-lengths the coefficient of transmissibility for dry air, $a_{a\lambda}$, the factor for the change produced by atmospheric vapor when the amount of precipitable water is 1 cm, $a_{w\lambda}$, and the theoretical values for dry air computed from the theory of molecular scattering.

TABLE IV

	Wave-Lengths								
	μ 0.370	μ 0.400	μ 0.430	μ 0.460	μ 0.500	μ 0.600	μ 0.750	μ 1.00	μ 1.50
$a_{w\lambda}$	0.957	0.962	0.967	0.971	0.976	0.977*	0.988	0.990	0.988
$a_{a\lambda}$ (observed)..	0.683	0.757	0.808	0.851	0.885*	0.916*	0.977	0.987	0.990
$a_{a\lambda}$ (computed)	0.680	0.755	0.808	0.850	0.890*	0.946*	0.977	0.987	0.986

* Places of selective transmission.

The corresponding values of a_λ for air containing w cm of precipitable water-vapor would be $a_{w\lambda}^{w} \cdot a_{a\lambda}$.

The transmission coefficient for dry air has been used for the determination of the number of molecules, N_0, per cc of a gas at 760 mm pressure and at 0° C. The result was

$$N_0 = 25.6 \times 10^{18}$$

corresponding very closely with the present best value from other methods, 27.1 billion-billion. This mode of analysis shows that for dry air, except where selective absorption occurs, the depletion of the beam from the sun or other celestial body, as observed in 1910 and 1911 at Mount Wilson, was caused almost wholly by molecular scattering. From 0.36 μ to 0.50 μ the depletion is practically wholly of this nature. Then come the great selective absorption bands which, except that near D, have been eliminated from this discussion. Even in the infra-red between these water-vapor bands, molecular scattering accounts for the observed depletion of radiation by the atmosphere.

The same analysis applied to atmospheric aqueous vapor shows that the observed absorption is very much too great to be accounted for by the number of water molecules present. The transmission coefficients found by various observers for liquid water, however (0.21 μ to 0.50 μ), are such as would be expected from this amount of water in vapor form. This leads to the inference that its absorption in liquid form in this region results from molecular scattering. The number of molecules, N_o, computed from the transmission coefficients of liquid water is about

$$N_o = 28.\times 10^{18}\,.$$

The increased absorption connected with atmospheric water-vapor and the departure of the transmission coefficients from strict proportionality to the inverse fourth power of the wave-length in the sense that the coefficients for smaller wave-lengths are too high leads to the inference that the vapor is loaded with something greater in size than molecules. This loading could be due to dust or ions, although there is not definite evidence why these should be proportional to the amount of water-vapor present.

The presence of nuclei, formed by the action of ultra-violet light on the moisture present in the air, seems perhaps the most satisfactory explanation.

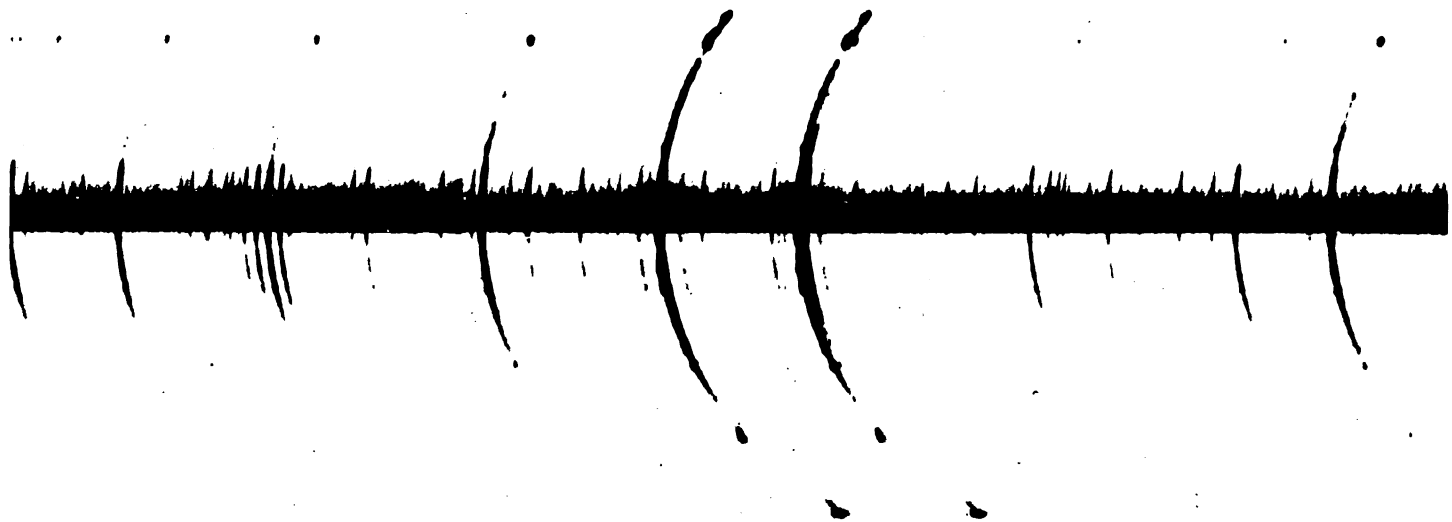
In the above study, as already stated, the amount of water-vapor present in the atmosphere was measured by the depths of three selective absorption lines in the infra-red. The effect of

scattering, which varies slowly and continuously with the wave-length, was eliminated. It was shown in an earlier paper[1] that the mean results of such determinations of the amount of aqueous vapor in the atmosphere agree with the mean results of estimates of it from observations with kites and balloons.

ASTROPHYSICAL OBSERVATORY
SMITHSONIAN INSTITUTION
WASHINGTON, D.C.
June 1913

[1] *Astrophysical Journal*, 37, 359, 1913.

PLATE XIII



Spectrum of Chromosphere—Region of H and K
Negative enlarged sixfold

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WAVE-LENGTHS OF THE CHROMOSPHERE FROM SPECTRA OBTAINED AT THE 1905 ECLIPSE[1]

By S. A. MITCHELL

The spectra with which the present paper deals were obtained on August 30, 1905, while the writer was a member of the United States Naval Observatory eclipse expedition. A special service squadron under command of Rear-Admiral Colby M. Chester, U.S.N. (then superintendent of the Naval Observatory), carried the party and their equipment across the Atlantic. Three separate stations were occupied; one at Guelma in Algeria, the other two in Spain. Of the two in Spain, one was located near the edge of the shadow-path at Poerti Coeli, the other near the central line of totality at the little town of Daroca. A preliminary account of the results obtained by the various parties has been published.[2]

The party at Daroca was under the general supervision of Professor W. S. Eichelberger, and the instrumental equipment was as follows: Forty-foot horizontal camera under the direction of Mr. L. G. Hoxton; time-service and longitude determination under the direction of Mr. Everett I. Yowell; various electrical and meteorological instruments under the direction of Professor F. H. Bigelow, U.S. Weather Bureau; and several spectroscopic instruments under the charge of the writer. The above-mentioned and Mr. C. P. Olivier were assisted in the erection and adjustment of the

[1] Printed in advance of the Naval Observatory report by permission from the Superintendent of the Naval Observatory.

[2] See C. M. Chester, *Astrophysical Journal*, 23, 128, 1906.

various instruments by the chief carpenter, the chief machinist, and four sailors from the U.S.S. "Minneapolis." About six weeks were spent in Daroca in preparation.

On the trip across the Atlantic, the officers and men of the "Minneapolis" were interested in the astronomical work by conferences and lectures. Five days before the day of the eclipse, the original party in Daroca was augmented by the arrival of officers and men from the ship, to the number of twenty-five. Officers were placed in charge of instruments with sailors to assist them. Frequent drills were held, and so thoroughly efficient was the service that everything passed off on eclipse day without a hitch.

As determined by Mr. Yowell, the position of Daroca was: longitude $=0^h 5^m 40^s.31$ W.; latitude $=41°6'29''.4$. For the determination of longitude, time signals were exchanged with the observatory of Madrid, a telegraph line being run to the eclipse camp, and the efficient services of the operator at Daroca, Señor Garcia, being freely put at the disposal of the eclipse observers.

The eclipses of 1900 and 1901 showed the efficiency of gratings, both plane and concave, for spectroscopic work. There are many advantages of gratings over prisms, chief of which may be mentioned (1) normal spectrum, (2) increased dispersion. For eclipse work, a slit is unnecessary, and used as an objective instrument, the amount of the astigmatism is a negligible quantity.

The spectrographic equipment consisted of five instruments, three of small dispersion and two of larger dispersion. The present paper will deal only with the large instruments. One of these was a plane grating, the other a concave grating.

PARABOLIC GRATING

This grating belongs to the Rumford Committee and was kindly loaned by Professor F. A. Saunders of Syracuse University. Instead of being ruled on a spherical concave surface, it was ruled on a parabolic surface. The grating was four inches in diameter, and had 14,438 lines to the inch. According to Mr. L. E. Jewell, its spectra were as brilliant as ordinarily obtained from a 6-inch grating, and its definition was equal to any Rowland grating he had ever seen.

The mounting of the grating was exceedingly simple. Light from the coelostat mirror was reflected horizontally to the grating and from there reflected and brought to a focus on the photographic plate. Grating and photographic plate were inclosed in a light-tight mahogany box. Exposures were made by a convenient flap shutter placed in the beam of light from the coelostat. If the photographic plate is perpendicular to the grating normal (and, consequently, parallel to the grating), the spectrum is normal.

The grating had a focal length of 5 feet (150 cm), corresponding to 10-foot radius of curvature in a concave grating. For focus, it was necessary to bend the plates to a radius of $2\frac{1}{2}$ feet (75 cm). It was, therefore, manifestly impossible to use glass plates, and the emulsion was coated on heavy gelatine films which were $1\frac{1}{4}\times 12$ inches (3×30 cm). Two plate-holders were used each holding six parallel strips. By repeated practice, it was possible in a fraction of a second to drop the plate-holder from one film to the next.

This instrument was focused by a collimator arranged by Mr. Jewell for the 1901 eclipse, and slightly altered as the result of experience gained in Sumatra. This collimator consisted essentially of two concave mirrors and a slit, so that by its means a parallel beam of light could be obtained from a slit-source. The collimator was first focused by a 5-inch visual telescope.

PLANE GRATING

To supplement the work of the parabolic grating, and particularly to gain information about the red end of the spectrum, a flat grating was used. This was a Rowland 6-inch grating belonging to the Naval Observatory. It had 15,000 lines per inch, with ruled lines $3\frac{1}{2}$ inches long. This grating was used by the writer in Sumatra in 1901. The definition was excellent.

Light from the coelostat mirror was reflected horizontally and fell on the grating. After reflection, the light was brought to a focus on the photographic plate by a Clark 5-inch visual lens of 72 (184 cm) inches focus. Grating, lens, and plate were inclosed in a light-tight mahogany box, and exposures were made, as with the parabolic grating, by a flap shutter. The spectra were brought to a focus almost in a plane, and it was therefore possible to use glass

plates, which were $1\frac{1}{2} \times 12$ inches (4×30 cm). Six plates were placed in parallel strips in each of two plate-holders. As with the parabolic grating, if grating and plate are each perpendicular to the line joining them, the spectrum is normal. Each of the boxes holding plane and parabolic gratings was inclined to the vertical in order to bring the line joining the sun's cusps approximately perpendicular to the length of the plate. As Daroca was not exactly on the central line of totality, a compromise was made for the positions at second and third contacts.

METHODS OF OBSERVING

Eclipse day, August 30, opened very auspiciously. First contact was observed under clear skies, but soon after, clouds had gathered. Five minutes before second contact, a large cloud obscured the sun, but it passed off before totality, and an uninterrupted view of the total phase was obtained. The citizens of Daroca gathered in great numbers, as closely as they could come to the eclipse camp. During the progress of the partial phase, each Spaniard present seemed bent on telling to his neighbor in a loud tone of voice the full details of what he knew about the subject. The noise of their conversation increased with the progress of the eclipse, and totality was greeted with such a shout that it was impossible to hear the counted seconds which should serve as guides to the exposures.

The plan had been for the writer to observe the disappearing crescent of the sun through a binocular, over one-half of which was arranged a plane mirror and plane grating combination, adjusted in such a way that with one eye through the binocular the crescent sun could be seen, with the other, its spectrum in the green region. This worked perfectly, and the word "Go" from him gave notice to the person counting seconds to restart his count. Two unlooked-for features were encountered: one being that the conversation of the Spaniards was rather loud, the second that the total phase occurred some ten seconds or more before it was expected.

It was planned to catch the "flash spectrum" with both instruments at the beginning and end of totality, to give two short exposures just before the first flash and, just after the second flash, one

long exposure at mid-totality, and others of varying length between. As above stated, each instrument had twelve plates. The program for each instrument was carried out practically as arranged.

THE DETERMINATION OF FOCUS

1. *Parabolic grating*.—This instrument was in the capable hands of Lieutenant Alfred G. Howe, U.S.N., who was assisted by two sailors from the "Minneapolis." Mr. Howe opened the shutter and made the exposures, one of the sailors shifted the plate-holder between exposures. the other sailor was stationed near the coelostat for the purpose of rendering assistance if any emergency arose. His help was not needed. The writer wishes to express to Mr. Howe his deep gratitude for the thoroughly efficient manner in which he handled the instrument.

This instrument was focused three days before the eclipse by the writer with the use of the collimator. It was, of course, possible to focus only in the visible region, a fluorescent eyepiece not being on hand. It was felt that the seasoned mahogany box, which held grating and photographical plate, could be fairly relied upon not to warp in the interval. In addition, the collimator was needed at the other Spanish station to focus its grating. No attempt was made to focus on stars, and it was felt to be unwise to leave the important operation of obtaining focus to the few hurried minutes just before totality while the cusps of the sun could be seen. The accuracy of focus will be seen from the photographs which are herewith reproduced. The flash spectrum is shown from λ 3300 to the D_3 line of helium. The focus at the violet end is hardly as sharp as it is from λ 4000 to the red end. The accuracy of the wave-length determinations speak louder than can any words concerning the sharpness of the spectra.

2. *Plane grating*.—On eclipse day, this instrument was handled by the writer with the help of two sailors who assisted as did the others for the parabolic instrument. An unfortunate accident occurred on the morning of the eclipse. The chief carpenter was requested to make two wooden braces to prop up the box and incline it at the proper angle to the vertical. (From the position of the box, it was more convenient to adjust for focus with the box

horizontal.) Through a misunderstanding, the carpenter nailed the braces to the box in the absence of the writer with the result that the focus was disturbed. Fortunately, however, the parts of the spectra in best focus are the red ends, though the focus is not as good as for the parabolic grating. Nevertheless the spectra were well measurable at this end and these are used to supplement the parabolic grating measures. On one of the spectra with the flat grating, the C-line (λ 6563) is seen.

SPECTRA

The photographs were developed in the dark room of the College of Daroca where running water was obtained. The writer wishes to express his thanks to Padre Felix Alvirez, the president of the college, for his many kindnesses. As the running water became rather warm in the daytime, it was necessary to develop at night. At 5:00 o'clock on the morning following the eclipse, the spectra were hung up to dry.

As above stated, the films for the parabolic grating were coated on heavy celluloid; for the flat grating, on glass. Lumière Panchromatic C was the emulsion used for the six films in the first plate-holder at beginning of totality, while Seed's Orthochromatic was used in the second plate-holder. For the plane grating instrument, Lumière Panchromatic C and Cramer Trichromatic were used in the two plate-holders respectively.

Results showed that the Lumière emulsion did not give the sensitiveness that had been expected from tests made before leaving home, so that the second plate-holder for each instrument gives more detail than the first in each case.

As the present paper is for the purpose of giving for the flash spectrum wave-lengths, intensities, etc., with as great an accuracy as possible, only one photograph with each instrument was measured. Those selected were the flash spectrum for each instrument at the end of totality. A future paper will deal with the spectra of chromosphere, corona, etc., which are given by the remainder of the plates.

The distinguishing features of the present spectra are (1) their good definition, (2) their normal dispersion, and (3) their extent,

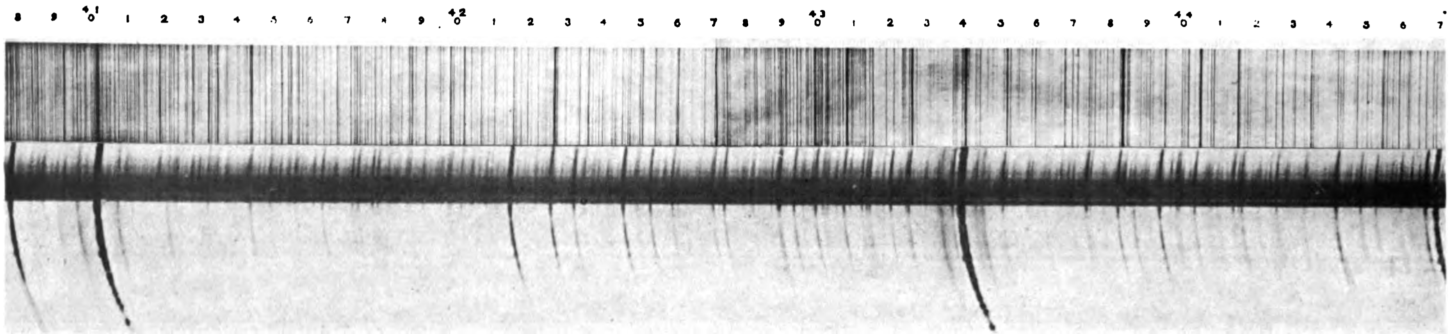
PLATE XIV

a

CHROMOSPHERIC SPECTRUM 1905 ECLIPSE

a. Positive nine-tenths natural size from λ 3700 to λ 5900

b



b. COMPARISON OF FRAUNHOFER AND CHROMOSPHERIC SPECTRA

Above—Rowland's atlas reduced fivefold

Below—Negative of chromospheric spectrum enlarged sixfold

from λ 3300 to D_3 for parabolic grating, and to λ 6200 for plane grating. The flash spectrum from the parabolic grating is shown in Plate XIV, *a*. In order to reproduce it on nearly the original scale much of the ultra-violet is omitted. This is reproduced as a positive when the lines are *bright*. For a more ready comparison with Rowland, the enlargements are negatives. It will be noticed at once from original and from enlargements that the continuous spectrum at the middle of the arcs was quite strong. Running down the center of this continuous spectrum is a small strip where the continuous spectrum is not so strong. This may be best seen in the green and orange regions. On the enlargements, particularly at the violet end, may be seen several parallel strips of continuous spectrum, one of considerable strength running through a prominence near the top, and several fainter strips through prominences below the center. Interesting differences will be noted by comparing the shapes of the various lines. The stronger lines like H and K and the hydrogen series show many protuberances. Chief among these may be mentioned a large prominence at the top of the photograph. H and K show a large prominence which was in violent motion and which was at such a high level that it is shown by none of the other lines.

On the original, most of the strong lines show a fine reversal at their centers.

MEASUREMENT OF SPECTRA

The spectrum obtained by means of the parabolic grating extends from λ 3318 to D_3, a distance of 9.5 inches (23.5 cm). From H to D_3 the distance is almost exactly 7 inches (17.78 cm). The dispersion is 1 mm = 10.8 angstroms, about equal to the three-prism dispersion near H_γ, of the Mills spectrograph of the Lick Observatory, or the Bruce spectrograph of the Yerkes Observatory. The dispersion with the flat grating is a trifle greater, and amounts to 9.1 angstroms per millimeter.

All measures were made by the writer at Columbia University. Most of the measures were made by the Repsold engine which has been extensively used at Columbia for the measurement of Rutherfurd photographs. A brass frame was made to carry the spectra. The measures consisted essentially in comparing the lines of the

spectra with a millimeter scale. All errors of the engine, such as division errors of the scale, errors of the micrometer screw, etc., have been most thoroughly investigated. About 10 per cent of the measures were made with the Gaertner machine for measuring stellar spectrograms, a machine similar to the ones used at Yerkes Observatory, and of which the important part is a long screw of half-millimeter pitch. Each measure consisted of the mean of two settings. Each spectrum was separately measured twice. Most of the parabolic grating spectrum was measured three times, considerable of it was measured four times, and some small regions were even measured five times.

The spectra being taken without slit, the lines instead of being straight were crescents, each crescent being a monochromatic image of the chromosphere. Manifestly, erroneous values of wave-lengths would be obtained if the micrometer wire when measuring was made to bisect each line of the spectrum. The chromosphere extends to different heights for different lines above the level defined by the edge of the moon projected on the sun. Exposures for the second flash were begun eight to ten seconds before the end of totality and continued to the end of totality. The flash spectrum is therefore not an instantaneous exposure, but a progressive one. Since the arcs of great elevation like H and K appeared, for the second flash, before those of lower elevation, the base of these arcs may be displaced a slight amount relative to the small low-lying arcs. In addition, for the strong heavy lines like H and K, there is a spreading-out of the photographic image due to irradiation caused by their relatively long exposure. Because of a realization of the above facts as the result of experience gained from similar spectra made in Sumatra for the eclipse of 1901, an attempt was made not to bisect each line, but rather to place the micrometer wire tangent to the spectral arcs on their concave side, which corresponds to the limb of the moon. With the more intense lines of the spectrum, an attempt was made to set the micrometer wire at a slight elevation above the limb of the moon, which, for the photographs measured, was toward the violet end. What success was obtained in this attempt at measurement may be seen by comparing the wave-lengths of the chromosphere with Rowland's values. For all lines

of the chromospheric spectrum taken with parabolic grating. having an intensity less than 25 on the assumed scale, the difference from Rowland averages but 0.02 angstrom, which corresponds to an error of measurement of 0.002 mm. For lines with intensities greater than 25, for the reasons just specified, there are greater differences. Usually for the intense lines, the chromospheric wave-length is too great. The reason for this is assumed to be simply an error in judgment in setting the measuring wire, not enough allowance having been made for the spreading of the heavy lines of the spectrum.

At second flash, the chromospheric light shone through a low-lying plane on the moon's edge. This plane had a sharp termination at one end and a gradual elevation toward the other. The result of this was that the short chromospheric arcs are sharply terminated at one end and gradually dwindle off toward the other. (The meaning of this will be more evident by reference to the photographs.) Advantage of this was taken in the measurements. This sharp termination of the arcs occurred exactly in their middle, as may be seen by looking at the longer arcs. At this sharp edge, the arcs were exactly perpendicular to the length of the spectrum, and consequently all measures for wave-lengths were made by setting the micrometer wire at this sharp termination of the arcs. Unfortunately, for the measurer, the continuous spectrum was rather strong throughout the spectrum and it became necessary to use a strong illumination. (The writer felt great hesitancy about using any chemicals to reduce the continuous spectrum, and he desired to measure the original spectra rather than copies.) This strong illumination tired the eyes rather quickly, and finally incapacitated the eyes for some time, thereby delaying the measurements.

The computing bureau of Columbia University, consisting then of Miss Flora E. Harpham, Miss Eudora Magill, and Miss Helen Lee Davis, assisted by recording and making the reductions to wave-lengths.

DETERMINATION OF WAVE-LENGTHS

Theoretically, both plane and parabolic grating spectra of the chromosphere are normal. Practically, they are not quite normal for the reason that the end of the plate-holder would have cut off

some of the incident light if adjusted to give the normal spectrum. The difference in scale at the two ends of the parabolic spectrum amounted to about one-half of 1 per cent. Consequently, for first approximations to wave-lengths, a constant scale-value was assumed; and setting this value up on a multiplying machine, we were able to obtain wave-lengths with the greatest ease.

During the measurement, it was found that the celluloid film of the parabolic spectrum was very sensitive to changes in temperature, the result being that it became necessary to reduce the lines measured at each sitting separately by themselves.

After obtaining approximate wave-lengths, it was necessary to reduce them to some consistent standard. It was felt that at the present status of the system of wave-lengths it was most advantageous to use Rowland's values. Consequently, comparisons were made with each and every well determined line in the chromosphere which corresponded to a *single* line, *not a blend*, in Rowland. These comparisons for a limited region of measures made at one sitting gave differences which were nearly constant.

The next step in the determination of wave-lengths was an accurate adjustment to Rowland's values. This was done by the well known method of Professor Carl Runge of the University of Göttingen, who, while these reductions were carried on, was Kaiser Wilhelm exchange professor at Columbia University. As each region considered was a comparatively small portion of the spectrum, the method consisted essentially in plotting the differences Mitchell—Rowland and passing a straight line through them. Instead of plotting their differences, the method was to use least squares to determine two constants corresponding to the intercept on the Y-axis and the slope of the tangent. Ordinarily from twenty to forty lines in Rowland could be used as standards. Generally at each sitting a few lines measured at the preceding sitting were remeasured.

Thus piece by piece the measures were reduced to Rowland's scale. Since wave-lengths from the measures at each sitting were reduced separately, the final wave-lengths as given in Table I are the means of the three or four separate measurements. Also, since each measurement was carried on absolutely independently of all

others with the spectra set at different readings of the scale, it is felt that the systematic differences from Rowland, if existing at all, are exceedingly small. For all lines with intensities less than 25, the differences Mitchell—Rowland taken without regard to sign averages almost exactly 0.02 angstrom. Taking account of signs, the average difference is excessively small, showing nothing systematic, except perhaps in some few limited regions.

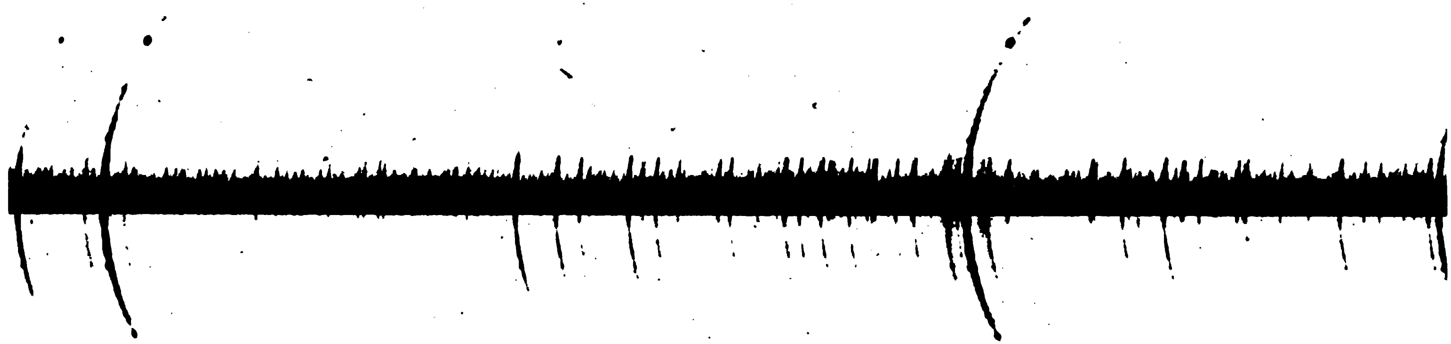
The differences between chromosphere and Rowland are the result of several causes: First, fundamental differences depending on the distribution of the vapor in the chromosphere. As stated above, there are believed to be no such fundamental differences of wave-length of appreciable size other than those caused by errors in judgment in knowing where to set the micrometer wire for the more intense lines. The second cause for the difference Mitchell—Rowland results from the uncertainty in knowing what wave-length to assume for Rowland for the blended lines. As will be shown later, there are enormous differences in intensities between the Fraunhofer spectrum and the chromospheric spectrum. Manifestly, on account of these differences in intensity, wrong values of wave-lengths would be obtained either by taking an average of the wave-length of the different lines blended, or by weighting them according to their intensities. But what wave-lengths are to be assumed for blended lines? This dilemma is well known to all investigators of stellar spectra. The only logical way for the writer to do was to adopt a rule and stick to it rigidly, and not try to manufacture a wave-length for each Rowland blended line considered. This rule was the one used by most spectroscopists, viz., to weight the lines according to their intensities in Rowland. If necessary to combine with a line 0 on Rowland's scale, this line should have weight 1, and 1 should be added to the intensities of each of the other lines. The third cause of discrepancy between Mitchell and Rowland was, of course, errors of measurement, both in Mitchell and Rowland. The writer sent a glass positive made from a contact print to Mr. John Evershed, and in *Kodaikanal Bulletin No. 27* he estimates the average difference between Mitchell and Rowland for well defined single lines in Rowland to be 0.01 angstrom (corresponding to 0.001 mm error of measurement).

INTENSITIES

The most characteristic difference between the chromospheric and the Fraunhofer spectra is in the intensities. The system of intensities for the chromospheric spectrum is purely an arbitrary one, in which 100 represents the strongest lines like K and H_γ, and 0 that of the weakest line. Naturally the intensities depend on the plate used, but allowance was partially made for the decrease in sensitiveness of the plate in the green and yellow regions. In estimating intensities, one is unconsciously influenced by the breadth of the lines, so that the values for intensity give a somewhat combined estimate of the blackness and breadth of a certain line. These at best are but estimates, but they are perhaps comparable in accuracy with estimates of intensities by others.

The reason for this characteristic difference in intensity is evident on a moment's reflection. Let us consider two different elements in the sun's envelope; one of these elements is low in density and extends high in miles above the sun's photosphere; the other is heavier and its molecules are contained in a shallower layer about the sun. It is easy to imagine that the absorption by the molecules of the two gases traversed by a beam from the sun might be the same, so that the two gases would give lines of equal intensity in the Fraunhofer spectrum. At the time of an eclipse, the exposure is a progressive one. The moon gradually passes before the sun, with the result that the exposure on the low-lying vapor is relatively very short compared with the other assumed vapor of greater elevation. And hence, it is readily seen that though the two gases may give lines of equal intensity in their absorption spectra, they will not do so in their emission spectra; the low-lying heavy vapor will give in the chromosphere short arcs of feeble intensity while the other assumed vapor will give longer arcs of greater intensity. Though there are other contributing causes, the main factor for the differences in intensity between the dark- and bright-line spectra of the sun is the heights to which the vapors extend. H and K and the hydrogen lines are the strongest in the chromosphere mainly for the reason that calcium and hydrogen extend higher than any other elements.

PLATE XV



SPECTRUM OF CHROMOSPHERE—REGION OF H_δ AND H_γ
Negative enlarged sixfold

In fact, there are such enormous differences in the two spectra that placed side by side, as they are in Plates XIV, *b*, the spectra seem to belong to stars of two different types, the chromospheric spectrum apparently being of an earlier type than the Fraunhofer spectrum.

In addition to the differences between lines of different elements which depend mainly on elevations, there are enormous differences among the lines of any one element in the two spectra. Generally, the stronger lines in the dark-line spectrum give the stronger lines in the chromospheric spectrum, but not always so. Almost without exception the enhanced lines, or those stronger in the spark than in the arc, give stronger lines in the chromosphere, the differences being generally quite marked. Leaving out of consideration the enhanced lines, one cannot predict from the intensity of a given line in Rowland's tables what the intensity of the line will be in the chromospheric spectrum. In short, in the two spectra, we are dealing with spectra taken under different electrical, thermal, and pressure conditions, and it is but natural to expect as a result that there will be vast differences in intensities.

The chief differences for the stronger lines are found in the elements helium and hydrogen. As is well known, no helium absorption lines are found in the sun. The whole hydrogen series is found in the chromosphere. Perhaps one of the most striking differences between the intensities of lines in the two spectra (which at the same time will illustrate the difficulty experienced in finding the wave-lengths of blended lines), will be seen by referring in Table I to a line in the chromosphere measured at λ 3709.50. In Rowland's tables is a line at λ 3709.389 belonging to *Fe* with an intensity 8. With chromospheric spectra of less accuracy than the present, one would naturally identify the chromospheric line at 3709.50 as a *Fe*-line, especially since this *Fe*-line has an intensity in Rowland of 8. But for the present spectrum, the discrepancy in wave-lengths is too great. The next line in Rowland's tables is an unidentified line at 3709.540 with an intensity 0N. Reference to Exner and Haschek's tables shows that this latter line is due both to *Zr* and *V*. In the arc, the lines of both elements are absent;

in the spark the intensity for *Zr* is 15, for *V* is 3. Although this line does not appear in Lockyer's list of enhanced lines, the intensities from Exner and Haschek show that both *Zr* and *V* are enhanced. Consequently, it is seen that the chromospheric line at 3709.50 more nearly corresponds to the weak line at 3709.540 than to the much stronger *Fe*-line at 3709.389. But what wave-length is to be assumed for the blended value of these two lines from Rowland? Manifestly an entirely erroneous value will be obtained if, according to the rule adopted (and given above), the *Fe*-line is given a weight of 9, the other of 1. To show the writer's inability to evaluate the blended line, both wave-lengths are given.

IDENTIFICATION OF LINES

The greatest possible care was exercised in an attempt to identify as many lines as possible of the chromosphere spectrum. While determining wave-lengths, it was necessary to make a close comparison with Rowland's Table of Solar Spectrum Wave-Lengths. To make the identification more complete and to gain information regarding the relative strength in arc and spark spectra, it became necessary to look up practically every table of metallic spectra that had ever been published. During the earlier part of this branch of the present work, the first edition only of Exner and Haschek's tables was published. To go beyond the limit of their wave-lengths (λ 4600), it became necessary to consult Kayser's *Handbuch der Spectroscopie*, Vol. 5 (the sixth volume being still in press), and original sources whenever available. Fortunately, before this part of the work was finished, the 1912 edition of Exner and Haschek's tables appeared, as well as the sixth volume of Kayser.

The method adopted was to take out from the above sources all lines of all metallic spectra which would have a line approximately close to the chromospheric line under investigation, putting down on paper at the same time the intensities in both arc and spark. This work naturally consumed a great amount of time. Upon the arrival of the later edition of Exner and Haschek's tables, a recomparison was made of those elements whose values were different in the two editions. The writer wishes here to express his

appreciation of these splendid volumes. For the purpose in hand, they left almost nothing to be desired. In order to make the present work more uniform, the values of intensities of arc and spark of Exner and Haschek have been adopted throughout.

After having tabulated the intensities of arc and spark from all available sources, it was necessary to choose from these the one or more arc and spark lines which appeared to agree with the lines of the chromosphere. This was a comparatively simple matter on account of the accuracy of wave-lengths of lines of the chromosphere, experience telling which of the possible identifications was the probable one.

In this part of the work many differences were found from the identification given in Rowland's tables, differences expected from the reasons that the present work deals with the chromospheric spectrum and not with the ordinary solar spectrum, and also from the fact that in the quarter-century since Rowland's work was completed, much has been learned concerning the spectra of the metals. Where Rowland has given identifications, they were in most cases found correct.

In Table I, in the column headed "Substance" is given the writer's opinion regarding the identification of the sources of lines in the chromosphere. Following the plan given in Rowland's tables, the sources are arranged in the order of their importance. If a hyphen is given, the first is the important source. If a comma is printed between the two elements, each substance has an equal value in fixing the source of the chromosphere line.

This close comparison with the spectra of the elements made the identification of lines rather certain. But Rowland's tables were made from spectra having a dispersion of approximately ten times the dispersion of the chromospheric spectrum (21-foot radius in the second order compared with 5-foot focus in first order, the gratings having nearly the same number of lines per inch). Naturally, lines which appear single in the chromospheric spectrum may be a blend of two or more lines with the greater dispersion. But lines which appear as a close pair or a blend in the chromosphere must be the result of the blend of corresponding lines in Rowland.

On account of the great differences in intensity of the chromospheric and Rowland spectra, it was difficult to be always sure of identifications until photographs were compared side by side. The original photograph of the flash spectrum was enlarged six times. Rowland's great atlas was reduced five times. Since the flash spectrum was nearly normal, it was possible to procure both spectra on a close approximation to scale. On Plate XIV, *b* are the two spectra printed side by side. This comparison of spectra will perhaps speak more strongly than any words or comparison of wave-lengths concerning the sharpness of the original spectrum of the chromosphere. On account of the small variations from the normal spectrum (noted above) it was impossible to obtain an exact match in scale. Those who are interested sufficiently will carry the comparison along line for line.

The photographs of chromospheric and solar spectra side by side were of the very greatest service in decisions on the relative importance of the sources of the lines of the flash spectrum. Perhaps of the greatest value was the information gained concerning the appearance of the lines in Rowland under the identical dispersion as obtained in the chromospheric spectrum, and from this it was possible to decide rather positively what lines in Rowland become blended under the smaller dispersion. In Table I, under "Intensities, Rowland," is given in parentheses the number of lines which are blended in Rowland's tables, the value of the intensity being naturally the total or combined intensity.

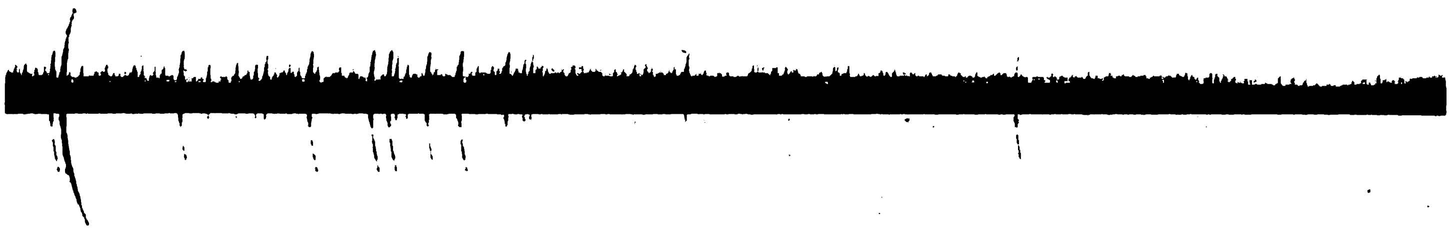
Under "Enhanced Lines," p. 487, will be found further details concerning intensities.

A leave of absence from Columbia University permitted the writer to be at the Yerkes Observatory during 1912–1913. While he was there, most of the identifications, etc., were carried out, and the photographic reproductions were made.

HEIGHTS OF CHROMOSPHERE

These slitless spectra give a ready means of determining the heights to which the vapors forming the chromosphere extend above the photosphere by measurement of the length of the

PLATE XVI



Spectrum of Chromosphere—Region Showing Hydrogen λ 4686
Negative enlarged sixfold

chromospheric arcs. For the values herewith given, the sun's semi-diameter was assumed to be 15′50″.7, the augmented semi-diameter of the moon, 16′35″.7. From these semi-diameters were calculated the heights corresponding to various half-lengths of arcs, and a table was constructed (which it is not necessary to print). A protractor was made on glass with a radius equal to that of the chromospheric arcs on the enlarged spectra above referred to. To obtain the length of the arcs, it was necessary only to lay the glass protractor on an enlarged print of the chromosphere and read off degrees from the protractor. The small table gave the corresponding height in kilometers.

The sharp termination of the chromospheric arcs referred to on p. 415 is very near to the middle of the longer arcs. It was assumed that this termination was at the middle of the arcs, and the half-lengths of the shorter arcs were accordingly measured. For the longer arcs, their whole lengths were measured.

In Table I, there is given in the first column the height, in kilometers, to which the chromospheric vapors extend. In the second and third columns are given the wave-lengths of the chromosphere and of Rowland (rounded off to two decimals). In the four last columns are given intensities, those in the two last columns being the values from Exner and Haschek's tables. Since Lockyer's tables of enhanced lines play an important rôle in spectroscopic work, a letter "L" in the "spark" column signifies that the line is an enhanced line according to Lockyer. In some cases, where Lockyer's intensities seemed more reliable than Exner and Haschek's, the estimates of intensity from the former are given. In order to save space in printing, the intensities of the various elements, where more than one form a line, are given in a horizontal line instead of a separate line for each element, as is usually the case in similar tables. The intensities are naturally given in the same order as in the column "Substance."

On the red side of D_3, wave-lengths depend on the plane grating spectrum only. On account of the poorer definition (see above), wave-lengths are given only to tenths of an angstrom instead of to hundredths.

TABLE I

Height of Chromosphere	Wave-Lengths: Chromosphere	Wave-Lengths: Rowland	Substance	Intensities: Rowland	Intensities: Chromosphere	Intensities: Arc	Intensities: Spark
km							
400....	3318.16	3318.16	*Ti*	6	2	3	5
300....	3320.42	3320.39	*Ni*	7	0	8	3
400....	3321.84	3321.84	*Ti*	4	2	2	5
600....	3323.03	3323.06	*Ti*	5	5	5	10
350....	3323.88	3323.88	*Fe*	3	0	2	1
400....	3324.19	3324.20	*Cr*	4N	1	1	3
450....	3326.87	3326.91	*Ti*	5	2	3	5
400....	3328.19	3328.25	*Y-Cr*	(2) 4	1d	20-1	30-3
400....	3328.99	3329.00	*Fe*	3	1	2	1
600....	3329.57	3329.57	*Ti-Co*	5	5	6-3	10–
500....	3332.25	3332.24	*Ti*	3	3	3	8
600....	3335.34	3335.32	*Ti*	(2) 6	5	5	10
400....	3336.45	3336.43	*Cr-Fe*	(2) 4	1	2–	5–
300....	3336.99	3337.03	*V, Cr*	(2) 1	0	1, 2	1, 1
300....	3337.51	3337.48	*La-Er-Co*	(2) 2	0	8-3-3	15-3-1
350....	3337.99	3337.98	*V-Ti*	2	0	–1	8-3
350....	3339.26	3339.27	*Fe-Ni*	(2) 3	0d	2–	...
500....	3339.89	3339.93	*Cr-Co*	3	3	2-4	10-2
600....	3340.48	3340.48	*Ti*	(2) 5	3	5	6
900....	3341.99	3342.01	*Ti*	(2) 8	8	4	10
500....	3342.77	3342.72	*Cr*	3	2	2	10
300....	3343.50	3343.48	*Sc*	00	0	1	3
500....	3343.86	3343.91	*Ti*	4	2	3	5
300....	3344.64	3344.66	*La*	2	0	8	8
300....	3344.95	3344.92	*Zr*	0	0	3	4
500....	3346.88	3346.88	*Ti-Cr*	(2) 5	2	3-3	5-1
500....	3348.00	3348.02	*Cr-Fe*	(2) 6	2	2–	6–
750....	{3349.15	{3349.17	*Ti*	(2) 5	4	3	8
1000....	3349.54	3349.58	*Ti-Cr*	(2) 9	10	8-1	10-2
500....	3353.90	3353.88	*Sc*	4	3	20	20
300....	{3354.47	{3354.52	*Co, Zr*	3	0	5, 2	4, 3
300....	3354.79	3354.78	*Ti*	3	0	8	3
350....	3355.37	3355.36	*Fe*	4	0	2	1
350....	3356.22	3356.23	*Zr*	1	1	4	4
400....	3357.50	3357.45	*Zr, Cr*	(2) 3	2	3, –	4, 4
400....	3358.63	3358.65	*Cr*	4	3	2	10
500....	{3360.18	{3360.18	*Zr*	2	2	2	4
500....	3360.50	3360.48	*Cr*	1	2	2	20
750....	3361.35	3361.35	*Ti-Sc*	(2) 10	8	10-10	30-8
300....	3362.11	3362.09	*Sc*	2	0	10	8
300....	3366.34	3366.31	*Ti, Ni*	6d?	0	1, 5	3, 3
450....	3366.96	3366.97	*Ni-Fe*	(2) 6	2d?	3-1	2-1
450....	3367.74	3367.75	–	(2) 1	0	...	...
600....	3368.20	3368.19	*Cr-Er*	5d?	5	3-8	20-4
400....	3369.05	3369.08	*Sc*	3d?	1d	15	10
300....	3369.76	3369.71	*Ni-Fe*	6	0	15-3	–2
500....	3371.85	3371.89	*Ti-Ni*	(2) 7	4d?	10-6	2-3
1000....	3372.98	3372.95	*Ti-Er*	(2) 10	12	4-20	20-10
300....	3374.77	3374.81	*Zr-Ni*	(2) 3	1	3-5	5-3
350....	3378.45	3378.48	*Cr-Zr*	2	1	1-1	5-3
400....	3379.49	3379.51	*Cr-Sc*	2	2	1-1	3-3

TABLE I—*Continued*

Height of Chromo-sphere	Wave-Lengths		Substance	Intensities			
	Chromo-sphere	Rowland		Rowland	Chromo-sphere	Arc	Spark
km							
500....	3379.98	3379.96	*Cr*	3	3	1	5
600....	3380.41	3380.42	*Ti*	(2) 6	3	5	8
300....	3380.85	3380.86	*Ni, Sr*	(2) 11	0N	13, 20	8, 30
600....	3382.83	3382.82	*Cr*	4	4	2	10
750....	3383.98	3383.95	*Ti*	3	8	3	20
350....	3385.21	3385.20	*Co-Er*	(3) 5	0	4-10	3-8
400....	3387.53	3387.55	*Fe*	2	1	1	1
600....	3388.04	3387.99	*Ti-Zr*	5d?	6	5-3	10-5
350....	3391.55	3391.58	*Cr*	2	1	2	5
400....	3392.12	3392.11	*Zr-Er*	2	2	10-4	20-5
350....	3392.74	3392.78	*Fe-V*	(2) 3	0	5-1	2-4
350....	3393.33	3393.29	*Zr*	1	0	3	4
500....	3393.94	3393.98	*Cr*	2	1	1	4
600....	3394.71	3394.72	*Ti*	(2) 6	5	4	10
350....	3395.50	3395.52	*Co*	(2) 5	0	8	5
300....	3396.50	3396.52	*Zr*	0	0	1	3
400....	3399.35	3399.38	*Fe, Zr*	2	0N	5, 3	2, 4
350....	3401.35	3401.31	*Ni*	1	0	3	1
500....	3402.54	3402.55	*Ti, Cr*	3	2N	1, 1	4, 4
600....	3403.49	3403.46	*Cr-Ni*	(3) 6	4	3−	15−
300....	3404.43	3404.46	*Fe*	(2) 5	1	5	2
300....	3404.92	3404.92	*Zr*	(2) 2	1	3	6
300....	3406.92	3406.94	*Fe-V*	5d?	0	4-2	1-1
300....	3407.34	3407.34	*Ti*	2	0	1	2
300....	3407.65	3407.64	*Fe-Gd*	(2) 7	0	10-5	4-5
600....	3408.94	3408.91	*Cr*	3	5	3	20
350....	3409.92	3409.95	*Ti*	2	2	1	3
350....	3410.36	3410.34	*Zr-Fe*	3	1	4-1	8-1
300..	3412.60	3412.61	*Co*	(2) 9	0	20	7
300.. Many faint lines	3415.06	....	...	...	0	...	...
300..	3416.02	....	...	...	0	...	...
300..	3416.58	....	...	...	0	...	...
300..	3420.33	....	...	...	1	...	...
600..	3421.37	3421.35	*Cr*	4	4	3	10
600..	3422.84	3422.85	*Cr-Fe-Ce*	(3) 7	5	3-3-3	20-2-2
300....	3423.85	3423.85	*Ni*	7	0	10	5
300....	3424.40	3424.43	*Fe*	4	0	4	2
300....	3425.13	3425.15	*Fe*	4	0	2	1
300....	3425.66	3425.72	—	2	0	...	...
300....	3426.46	3426.50	*Fe*	(2) 6	0	3	1
500....	3430.70	3430.67	*Zr*	1	3	4	10
400....	3431.72	3431.72	*Co, Zr*	4	0	8, 1	4, 3
450....	3432.56	3432.55	*Zr*	00	1	1	4
600....	3433.48	3433.45	*Cr*	3	8	2	5
300....	3436.05	3436.10	*Cr*	(3) 3	0N	5	4
400....	3437.35	3437.34	*Ni-Fe*	(2) 8	1d	8−	5-1
500....	3438.36	3438.38	*Zr*	2	3	8	20
350....	3439.11	3439.13	*Mn-Fe*	(2) 4	1d	1−	3−
400....	3440.13	3440.14	*Gd*	000N	1	8	6
500....	3440.75	3440.76	*Fe*	20	2	30	4
500....	3441.15	3441.16	*Fe*	15	2	30	4

TABLE I—*Continued*

Height of Chromo-sphere	Wave-Lengths: Chromo-sphere	Wave-Lengths: Rowland	Substance	Intensities: Rowland	Intensities: Chromo-sphere	Intensities: Arc	Intensities: Spark
km							
600....	3442.12	3442.12	*Mn*	6	7	2	30
400....	3443.37	3443.33	*Co*	0	1	3	3
500....	3444.03	3444.02	*Fe*	8N	2	15	3
500....	3344.44	3444.47	*Ti*	4	3	4	10
300....	3445.20	3445.26	*Fe*	5	0	5	2
350....	3445.69	3445.74	*Cr-Dy*	2N	0	3-10	2-3
500....	3446.38	3446.41	*Ni*	15	2	30	10
300....	3446.54	3446.54	–	1Nd?	0	...	...
300....	3447.43	3447.42	*Zr-Fe*	4	0	3-2	3-1
300....	3449.00	3449.00	*Y*	0	0	5	5
300....	3449.60	3449.58	*Co*	6d?	0	10	5
300....	3450.52	3450.47	*Fe-Gd*	5	0	3-6	1-6
300....	3452.04	3452.06	*Fe*	3	0	3	1
400....	3452.60	3452.61	*Ti*	1	2	1	8
300....	3453.02	3453.04	*Ni*	6d?	0	10	5
300....	{3453.45	{3453.47	*Cr*	0	0	3	2
300....	{3453.69	{3453.65	*Co*	(2) 5	0	20	10
300....	3454.32	3454.30	*Ti*	1	0	1	1
300....	3455.43	3455.38	*Co*	5	0	3	3
300....	3455.91	....	...	...	0	...	...
350....	3456.16	3456.15	*Er-Nh*	∞	1	6-30	2-30
400....	3456.59	3456.53	*Ti*	3	3	2	10
300....	3457.78	3457.72	*Zr-Cr*	0	0	3–	6-4
350....	3458.51	3458.56	*Ni-Fe*	(2) 11	1d	20-2	10-1
350....	3459.10	3459.07	*Zr*	∞	0	2	5
400....	3459.56	3459.57	*Ce-Fe*	2	1	–1	4–
350....	3460.05	3460.06	*Zr-Fe*	(3) 6	0	3-2	2-1
400....	{3461.59	3461.63	*Ti*	5	3	3	10
400....	{3461.78	3461.80	*Ni*	8	3	20	10
300....	3462.92	3462.95	*Co*	6	0	10	5
300....	3463.27	3463.30	*Zr-Fe*	(2) 2	1d	3-1	15–
300....	3464.21	3464.27	*Sr-Gd-Er*	(3) 4	1N	30-6-4	50-6-2
500....	3465.89	3465.90	*Co*	4	2	10	5
350....	3468.95	3468.99	*Fe*	2	0d?	1	1
350....	3471.42	3471.45	*Zr-Co*	(2) 6	0	3-3	4-2
500....	3473.75	3473.74	*Fe?*	(3) 2	2	...	...
600....	3474.27	3474.24	*Mn*	4	5	1	15
300....	3475.29	3475.27	*Cr*	2	0	1	3
400....	3475.56	3475.59	*Fe*	10	2	10	3
400....	3476.85	3476.85	*Fe*	8	0	10	3
500....	3477.32	3477.32	*Ti*	5	4	3	10
300....	3478.74	3478.74	*Zr*	(2) 1	0	1	2
350....	3479.55	3479.53	*Zr*	2	1	4	10
300....	3480.53	3480.55	*Zr-Er*	(2) 3	0	2-3	3-3
300....	3481.04	3481.02	*Ti*	2	0	...	2
400....	3481.35	3481.30	*Zr*	2	2	4	15
500....	3483.06	3483.05	*Mn–*	5d?	4	2–	12–
350....	3483.79	3483.78	*Zr-Ni-Co*	(3) 9	1N	3-8-4	7-4-3
300....	3485.10	3485.12	*Fe*	(3) 4	0	1	...
300....	3485.50	3485.49	*Fe, Co, Zr*	6	0	3, 4, –	2, 3, 3
300....	3486.07	3486.04	*V-Ni*	5	0	2-5	6-2

TABLE I—*Continued*

Height of Chromo-sphere	Wave-Lengths		Substance	Intensities			
	Chromo-sphere	Rowland		Rowland	Chromo-sphere	Arc	Spark
km							
400....	3488.22	....	...	...	1	...	...
500....	3488.80	3488.82	*Mn*	4	4	2	10
350....	3489.56	3489.55	*Co*	5	0	20	8
400....	3489.87	3489.84	*Ti, Fe*	(2) 5	3	1-2	2-1
400....	3490.75	3490.73	*Fe*	10N	3	20	4
500....	3491.20	3491.20	*Ti*	5	4	3	5
350....	3493.06	3493.11	*Ni*	10	1	30	10
350....	3493.27	3493.31	*V*	0N	1	2	5
300....	3494.32	3494.31	*Fe*	2	0	...	...
300....	3494.78	3494.82	*Fe*	2	1	...	...
350....	3495.41	3495.46	*Cr-Fe*	(2) 5	2d?	1-3	3-1
400....	3495.80	3495.82	*Co-Ti*	(2) 5	2	5-1	5-1
500....	3496.32	3496.32	*Zr-Y*	(2) 2	4	10-10	20-10
350....	3497.13	3497.15	*V*	1	1	2	8
400....	3497.71	3497.67	*Mn*	3	2	1	6
300....	3498.86	3498.89	–	1	0	...	...
350....	3499.27	3499.25	*Er-Ti*	0	1	15–	10-1
400....	3500.57	3500.57	*Ti-Fe*	(2) 5	1d	1-1	2-1
300....	3501.03	3501.00	*Ni-V*	6d?	0	6-2	4-2
300....	3502.62	3502.56	*Co-Ni*	(4) 10	0d	19-3	9-1
400....	3504.58	3504.58	*V*	2	2	3	1
600....	3505.05	3505.06	*Ti*	2	5	3	30
400....	3505.76	3505.75	*Zr-V*	(2) 1	1d	5-3	20-2
350....	3506.57	3506.56	*Co-Fe-Ti*	(3) 9	0d	10-2-2	8-1-1
350....	3508.56	3508.59	*Fe*	(3) 6	0d	2	1
350....	3510.00	3509.99	*Co*	4	1	8	5
400....	3510.45	3510.47	*Ni*	8	1	15	10
600....	3511.02	3510.98	*Ti*	5	5	3	30
300....	3512.00	3511.98	*Cr-Mn*	2	0	1-1	4-1
350....	3512.76	3512.78	*Co*	6	1	10	6
350....	3513.66	3513.62	*Co*	5	1	4	4
350....	3513.99	3513.97	*Fe*	7	1	10	3
350....	3514.18	3514.14	*Ni*	3	1	5	8
500....	3515.14	3515.14	*Ni-Fe*	(2) 14	2d	30-1	10–
300....	3516.36	3516.36	*Ni*	2	0	2	1
300....	3516.70	3516.70	*Fe*	2	0	1	...
400....	3517.48	3517.45	*V-Ce*	3	2	3-3	20-2
300....	3518.95	3518.92	*Fe*	(2) 6	0	2	...
400....	3519.87	3519.90	*Ni-Zr*	7	2d?	6-4	3-3
500....	3520.38	3520.40	*Ti*	2	3	2	8
300....	3521.01	3520.99	*Zr*	2	0	...	3
300....	3521.48	3521.50	*Fe–*	(2) 11	1	10	3
300....	3521.86	3521.83	*Co-V*	(2) 6	0	3-1	5-5
300....	3523.08	3523.05	*Fe, Co*	2	0	1, 2	–, 1
500....	3524.04	3523.99	*Co-Fe*	(3) 10	2d	4-2	5-4
500....	3524.66	3524.68	*Ni*	20	3	50	15
300....	3524.92	3524.88	*V*	1	0	2	8
400....	3525.91	3525.91	*Zr–*	(2) 6	1	2	4
400....	3526.45	3526.45	*Fe*	(4) 9	1	7	3
300....	3527.92	3527.94	*Fe*	5	0	3	1
350....	3529.13	3529.14	*Co-Ni*	(2) 4	1	5–	3–

TABLE I—*Continued*

Height of Chromosphere	Wave-Lengths		Substance	Intensities			
	Chromosphere	Rowland		Rowland	Chromosphere	Arc	Spark
km							
350....	3529.85	3529.85	*Co-Fe*	(3) 9	1	15-3	6-1
500....	3530.86	3530.92	*V*	3	2	3	20
500....	3531.76	3531.82	*Mn-Dy-Fe*	(3) 6	2d	3-20-	3-20-
300....	3532.64	3532.72	*Fe, V*	4	0	1, –	–, 3
400....	3533.35	3533.33	*Fe-Co*	(3) 17	0d	7-5	3-4
300....	3534.03	3534.00	*Ti*	1	0	...	2
350....	3535.05	3535.06	*Fe*	3	1	1	...
500....	3535.55	3535.55	*Ti*	4	5	2	15
400....	3535.83	3535.87	*Sc*	3	1	10	15
350....	3536.70	3536.71	*Fe*	7	1	5	3
300....	3538.40	3538.40	*V*	1	0	1	4
350....	3541.22	3541.24	*Fe*	7	0	8	3
350....	3542.30	3542.29	*Fe*	(2) 9	0	8	3
300....	3543.50	3543.47	*Co-Fe*	(2) 4	0	5-1	...
350....	3544.19	3544.16	*Ce-C*	000	0	...	3-
500....	3545.33	3545.34	*V*	4	3	3	30
350....	3545.83	3545.85	*Fe-Gd*	(2) 8	1	3-10	1-10
300....	{3547.41	3547.36	*Fe-C*	3	0d?	1	...
350....	{3548.10	3548.14	*Mn-Ni*	(3) 13	1	23-3	10-3
400....	3549.12	3549.15	*Y*	2	2	10	20
350....	3549.52	3549.51	*Gd-C*	0	0	10	10
300....	3550.73	3550.74	*Co*	4	0	5	3
350....	3551.55	3551.59	*Ni-C*	(2) 5	1	3-	2-
350....	3552.06	3552.10	*Zr*	1	2	6	20
300....	3553.15	3553.13	*Co*	1	0	3	2
350....	3554.25	3554.26	*Zr-Fe*	5	0	-3	4-1
350....	3555.06	3555.08	*Fe*	9	0	8	4
350....	3555.23	3555.18	*C-*	0	1	...	...
400....	3556.16	3556.09	*C*	000Nd?	1	...	...
500....	3556.85	3556.89	*V, Zr-Fe*	(4) 11	4	3, 8-5	50, 20-2
350....	3557.94	....	...	...	0	...	...
500....	3558.66	3558.67	*Sc, Fe*	8	2	20, 10	20, 4
300....	3559.24	3559.22	*Fe-C*	1	0	1-	...
300....	3559.64	3559.66	*Fe*	3	0	1	...
350....	3561.05	3561.04	*Co, Ce*	4	1	4, 4	4, 4
400....	3561.54	....	*C*	...	0	...	...
300....	3562.02	3562.04	*Ti*	1	0	1	2
350....	{3564.61	{3564.66	*Ti*	3	1	1	...
500....	{3565.49	{3565.54	*Fe*	20	4	20	5
300....	3566.08	3566.11	*Ti*	1	0	1	3
350....	3566.28	3566.31	*V*	2N	1	2	8
300....	3567.14	3567.14	*Fe*	(2) 3	0	1	2
400....	3567.90	3567.88	*Sc*	2	2	20	20
300....	3568.73	3568.78	*Fe*	(2) 6	0N	1	...
500....	{3569.69	{3569.65	*Co, Mn*	(3) 11	3	20, 25	10, 9
500....	{3570.34	{3570.27	*Fe*	20	3	50	10
400....	3572.10	3572.08	*Ni, Fe*	(2) 11	1	10, 3	3, 2
500....	3572.66	3572.67	*Sc-Zr*	(2) 10	5	30-8	50-15
300....	{3573.53	{3573.54	} *Fe-Ti*	(5) 12	{ 0 }	4-2	3-2
400....	{3574.11	{3574.05			2		

TABLE I—*Continued*

Height of Chromosphere	Wave-Lengths		Substance	Intensities			
	Chromosphere	Rowland		Rowland	Chromosphere	Arc	Spark
km							
300....	3574.57	3574.56	*V-La-C*	1	0	-3-	3-1-
400....	3575.49	3575.53	*Fe-Co*	(7) 16	1	4-3	2-5
600....	3576.52	3576.53	*Sc*	3	6	20	30
350....	3577.03	3577.00	*Zr*	1	2	5	15
400....	3577.96	3578.01	*Mn-V*	5	2	10-3	5-2
400....	3578.36	3578.36	*Zr-Ti*	00	1	-1	3-1
500....	3578.87	3578.83	*Cr*	10	3	30	20
600....	3581.11	3581.07	*Sc*	5	3	10	20
600....	3581.36	3581.35	*Fe*	30	4	50	10
300....	3582.12	3582.08	*Zr-Fe*	(3) 8	0	-2	3-2
350....	3582.47	3582.47			1		
350....	3584.01*	3584.05	*C-*	3	0	...	...
450....	3584.82	3584.80	*Fe*	6	3	4	2
450....	3585.09	3585.10	*Fe, Gd*	6	3	2, 10	2, 10
600....	3585.44	3585.41	*Cr, Fe*	(2) 12	5	4, 5	4, 3
300....	3585.76†	3585.81	*Fe-Cr-C*	(2) 8	0	5-	3-3-
300....	3586.67	3586.68	*Mn*		0	5	4
400....	3586.97	3587.02	*Al-Fe*	(6) 24	1	-8	100-3
400....	3587.34	3587.37	*Co*		1	15	10
350....	3587.68	3587.78	*Fe-C*	(2) 8	0	3	2
350....	3588.12	3588.08	*Ni-Zr*	6	0	3-3	2-3
350....	3588.76	3588.76	*Fe*	4	0	3	1
350....	3589.27	3589.25	*Fe*	4	1	4	1
600....	3589.86	3589.84	*V-Sc*	(2) 10	8	4-10	20-10
500....	3590.62‡	3590.63	*Sc-Gd-C*	(2) 4	2N	15-4	10-4
400....	3591.57	3591.56	*Fe*	(2) 4	1d	1	...
450....	3592.13	3592.17	*V*	2	3	3	20
350....	3592.81	3592.82	*Gd-Fe*	4	0	6-1	8-
500....	3593.55	3593.60	*V, Cr*	(2) 12	4	2, 30	15, 20
400....	3594.92	3594.86	*Fe-Co*	(2) 9	1d	4-8	2-4
350....	3595.34	3595.38	*Mn-Fe*	(2) 3	0	4-	2-
500....	3596.17	3596.20	*Ti*	4	4	3	5
350....	3597.17	3597.19	*Fe*	5d?	0	1	...
350....	3597.85	3597.85	*Ni*	8	1	10	6
350....	3598.29	....	...	...	0	...	...
350....	3599.36	3599.36	*Fe*	(4) 9	1d	2	1
400....	3600.28	....	...	...	1	...	...
600....	3600.91	3600.88	*Y*	3	6	20	50
600....	3602.03	3602.06	*Y*	4	1	10	20
300....	3602.64	3602.65	*Fe*	(2) 7	0N	3	3
350....	3603.31	3603.35	*Fe*	5	1	4	3
500....	3603.95	3603.92	*Cr*	3	4	...	10
350....	3604.70	....	*C*	...	0	...	...
500....	3605.48	3605.48	*Cr*	7	3d	30	20
400....	3606.83	3606.84	*Fe-*	6	1	8	4
300....	3607.60	3607.60	*Zr-Mn*	(2) 3	0d	2-5	5-3
500....	3609.00	3609.01	*Fe*	20	3	20	6
300....	3609.50	3609.47	*Ni*	5d?	0	5	2

* Third edge of fourth cyanogen band.
† Second edge of fourth cyanogen band.
‡ First edge of fourth cyanogen band.

TABLE I—*Continued*

Height of Chromo-sphere	Wave-Lengths		Substance	Intensities			
	Chromo-sphere	Rowland		Rowland	Chromo-sphere	Arc	Spark
km							
400....	3609.70	3609.63	*Sa-Pd*	(2) 3	1	4-100	4-50
500....	3610.55	3610.56	*Ti-Fe-Ni-Mn-Cd*	(5) 19	2N	4-6-10-5-500	2-3-4-3-100
500....	3611.20	3611.19	*Y*	2	3	20	30
350....	3611.95	3611.92	*Zr-Co*	(2) 2	1	3-4	10-2
350....	3612.86	3612.88	*Ni*	6d?	1	6	3
750....	3613.96	3613.95	*Sc*	4	10	30	100
400....	3614.89	3614.92	*Zr*	2	2	4	10
350....	3616.71	3616.71	*Er-Fe*	4	0	10-1	8-1
400....	3617.96	3617.93	*Er-Fe*	6	1	5-4	5-3
600....	3618.91	3618.92	*Fe*	20	6	20	6
350....	3619.56	3619.54	*Ni*	8	2	50	15
300....	3619.90	3619.92	*Fe*	2	0	...	...
300....	3620.37	3620.39	*Fe*	2	0	...	...
300....	3620.60	3620.61	*Fe-Gd*	3	0	1-3	1-3
450....	3621.32	3621.34	*V-Co*	2	3	1-1	6-4
400....	3622.13	3622.15	*Fe*	6	2	4	3
400....	3623.44	3623.43	*Fe*	(2) 7	1d	4	2
350....	3623.99	3623.95	*Zr-Mn*	(2) 5	0	5-4	4-2
400....	3624.53	3624.56	*Ni-Ca*	(3) 10	1d	3-10	2-2
500....	3624.98	3624.98	*Ti-Fe*	5	8	2-1	8–
400....	3627.99	3627.95	*Co, V*	4	1	5–	4, 3
400....	3628.85	3628.85	*Y*	2	2	10	10
500....	3630.15	3630.16	*Zr*	1	2	1	5
750....	3630.87	3630.88	*Sc*	4	12	20	100
600....	3631.61	3631.60	*Fe*	15	6	20	6
400....	3632.15	3632.16	*Fe-Er*	(2) 5	1	3-5	2-4
400....	3632.80	3632.77	*Fe-Cr*	(2) 4	0	2-3	1-2
500....	3633.27	3633.28	*Y*	2	2	20	30
400....	3633.61	3633.65	*Zr-Ti*	00Nd?	0	–2	6-1
400....	3634.40	(3634.39)	*He*	...	1	...	...
350....	3635.49	3635.51	*Ti-Fe*	(2) 6	1d	17-1	4-1
350....	3636.32	3636.33	*Fe*	(2) 5	0	2	1
350....	3636.70	3636.69	*Zr-Cr*	(2) 3	1	1-4	4-3
350....	3638.45	3638.44	*Fe*	3	0	4	1
350....	3639.56	3639.56	*Co*	2	0	3	2
350....	3639.94	3639.94	*Cr–*	2	0	5	5
400....	3640.55	3640.54	*Fe*	6	2	5	3
600....	3641.48	3641.47	*Ti*	4	8	3	10
500....	3641.95	3641.96	*Cr-Co*	(2) 2	1	3-3	3-1
600....	3642.88	3642.84	*Sc-Ti*	(2) 9	8	20-15	50-3
400....	3644.54	3644.55	*Ca*	5	0	20	4
600....	3644.97	3645.01	*Fe, Ca*	(3) 6	2d	–, 8	1, –
600....	3645.48	3645.48	*Sc*	3	4	15	15
400....	3646.31	3646.34	*Ti, Gd*	1	0d?	2, 15	2, 12
350....	3647.11	3647.13	–	2	0	...	...
400....	3647.54	3647.56	*Fe*	4	1	1	1
600....	3647.94	3647.99	*Fe*	12	5	30	6
400....	3649.70	3649.65	*Fe, La*	5	0	3, 2	3, 1
400....	3650.32	3650.31	*Fe-La*	(2) 9	0	2-3	4-4
400....	3650.87	(3650.90)	*Zr*	...	0	...	4

TABLE I—*Continued*

Height of Chromosphere	Wave-Lengths		Substance	Intensities			
	Chromosphere	Rowland		Rowland	Chromosphere	Arc	Spark
km							
400....	3651.60	3651.61	*Fe*	7	1	5	3
600....	3651.90	3651.94	*Sc*	4	4	10	20
500....	3653.62	3653.64	*Ti*	5	1N	15	4
350....	3654.07	3654.05	*Cr*	2	1	2	3
350....	3654.80	3654.76	*Ti, Gd*	(2) 3	0	3, 8	2, 8
400....	3655.78	3655.80	*Zr*	3	2	...	4
400....	3656.33	3656.39	*Cr-Fe-Gd*	(2) 5	2	2-8	3-2-8
400....	3656.80	(3656.81)	H_{35}	...	1	...	...
400....	3657.40	(3657.41)	H_{34}	...	1	...	...
400....	3658.19	(3658.07) 3658.24	H_{33} *Ti*	... 1	1d	... 4	... 3
400....	3658.80	(3658.78)	H_{32}	...	1	...	...
750....	3659.88	3659.90	*Ti**	5	5d	2	10
500....	3660.47	(3660.42) 3660.47	H_{30} *Fe*	... 2	1	... ...	... 1
500....	3661.42	(3661.38)	H_{29}	...	2	...	...
750....	3662.37	(3662.40) 3662.38	H_{28} *Ti*	... 5	4	... 2	... 10
350....	3663.07	....	...	...	0	...	...
750....	3663.56	(3663.56) 3663.51	H_{27} *Fe*	... (3) 9	2	... 2	... ...
1500....	3664.80	3664.76 (3664.82)	*Y-Gd* H_{26}	2 ...	4	20-8 ...	20-15 ...
350....	3665.41	....	...	...	0	...	...
1500....	3666.23	(3666.24)	H_{25}	...	3	...	...
350....	3666.88	3666.91	*Fe*	3	0	1	...
500....	3667.40	3667.40	*Fe*	4	1	2	1
1500....	3667.91	(3667.83)	H_{ω}	...	4	...	...
500....	3668.69	3668.63	*Zr, Y*	00	1	–, 3	4, 10
1500....	3669.60	(3669.61)	H_{ψ}	...	5	...	...
350....	3670.26	3670.24	*Fe*	2	0	2	1
350....	3670.60	3670.57	*Ni*	5	1	4	2
1500....	3671.45	3671.41 (3671.62)	*Zr* H_{χ}	0 ...	6d	2 ...	10 ...
350....	3671.82	3671.82	*Ti*	3	1	4	3
350....	3673.22	3673.23	*Fe-Er*	3	1	–1	–2
1500....	3673.96	(3673.91)	H_{ϕ}	...	5	...	...
500....	3674.84	3674.86	*Zr-V*	1	2	3–	15-3
350....	3675.47	3675.43	*Sc*	1	0	2	1
1500....	3676.48	3676.46 (3676.51)	*Co-Fe* H_{υ}	6 ...	6	1-3 ...	6-1 ...
400....	3677.51	3677.52	*Fe*	(2) 7	1	2	3
500....	3677.94	3677.91	*Cr*	(2) 6	4	2	6
2000....	3679.48	(3679.50)	H_{τ}	...	8	...	...
500....	3680.08	3680.07	*Fe*	9	2	10	3
350....	3681.11	3681.08	*Fe–*	(3) 9	1	3	4
500....	3682.35	3682.38	*Fe*	5	2	5	3
2000....	3682.96	(3682.95)	H_{σ}	...	10	...	...
6000....	3685.41	3685.34	*Ti*	10d?	40	8	100
600....	3686.24	3686.23	*Fe, V*	(2) 9	3	3, 3	2, 3

* H_{31} at λ 3659.57.

TABLE I—*Continued*

Height of Chromosphere	Wave-Lengths: Chromosphere	Wave-Lengths: Rowland	Substance	Intensities: Rowland	Intensities: Chromosphere	Intensities: Arc	Intensities: Spark
km							
2000....	3686.97	(3686.98)	H_ρ	...	12	...	...
400....	3687.76	3687.72	*Fe-V*	([2]) 10	1	10-10	5-3
400....	3689.64	3689.61	*Fe*	6	1	3	2
2500....	3691.78	(3691.70)	H_π	...	15	...	...
400....	3692.38	3692.36	*V*	1	1	10	4
350....	3692.81	3692.79	*Er-Fe*	2	0	20-1	10-
350....	3693.16	3693.17	*Fe*	3	0	1	...
500....	{3693.62	{3693.62	*Co*	1	2	5	4
500....	3694.27	3694.24	*Fe-Ni-*	([4]) 10	4	4-3	2-
400....	3695.11	....	...	...	1	...	...
3000....	3697.35	(3697.30)	H_o	...	20	...	...
500....	3698.28	3698.30	*Zr-Ti*	2	2	3-1	20-1
350....	3699.30	3699.28	*Fe*	3	0	1	...
350....	3700.53	3700.48	*V*	1	1	1	8
350....	3701.23	3701.23	*Fe*	8	0	4	2
350....	3702.41	3702.40	*Co, Ti*	([2]) 4	1	5, 2	6, 2
4000....	3704.03	(3704.00)	H_ξ	...	25	...	...
750....	3705.11	(3705.15)	*He*	...	1	...	...
750....	3705.71	3705.71	*Fe*	9	4	20	4
750....	3706.25	3706.24	*Mn-Ti-Ca*	([2]) 9	10	2-2-10	50-8-50
400....	3707.22	3707.19	*Fe*	5	1	2	1
400....	3708.08	3708.07	*Fe*	5	1	20	4
350....	3708.83	3708.85	*V-Ti*	([2]) 2	0	3-1	2-1
400....	3709.50	{3709.39	*Fe*	8 }	4	{20	4
		3709.54	*Zr-V*	0N }		...	15-3
600....	3710.49	3710.43	*Y*	3	8	30	100
6000....	3712.20	(3712.12)	H_ν	...	30	...	...
500....	3713.03	3713.06	*Cr*	([2]) 5	4	1	6
300....	3713.65	3713.69	*La*	000N	1	4	6
450....	3714.99	3714.93	*Zr*	0	2	1	6
600....	3715.57	3715.61	*V*	4	4	3	20
400....	3716.53	3716.59	*Fe-Ce-Gd*	7	2N	3-3-5	2-3-4
400....	3717.54	3717.54	*Ti*	2	1	5	2
350....	3717.96	3717.98	–	0	1	...	...
400....	3718.54	3718.55	*Fe-Ce*	4	2	2-3	1-3
1500....	3720.08	3720.08	*Fe*	40	10	50	10
6000....	3722.20	(3722.08)	H_μ	...	35	...	...
400....	3722.69	3722.69	*Fe-Ti-Ni*	([2]) 10	2	20-3-5	4-3-1
350....	3723.69	3723.68	*Nd-*	([2]) 2	2	4	3
400....	3724.20	3724.23	*Ti*	1	2	...	2
400....	3724.54	3724.53	*Fe-Er*	6	2	3-3	2-4
350....	3725.14	3725.13	*Ti-Ni-Eu*	([2]) 2	2	4-1-30	3-1-20
400....	3727.12	3727.14	*Fe*	([2]) 7	1	3	2
450....	3727.53	3727.55	*V-*	([3]) 2	2	2	20
500....	3727.82	3727.79	*Fe-Zr*	([2]) 5	3	15-	5-7
350....	3728.52	3728.54	*V-Ce*	00	1	1-3	4-3
350....	3730.00	3729.95	*Ti-Zr*	3	0	8-	4-3
350....	3730.53	3730.57	*Co-Fe*	([2]) 5	1	5-2	5-1
350....	3731.34	3731.32	*Zr-Fe*	([3]) 6	2	-4	15-2
350....	3732.12	3732.15	*Cr-Mn*	([2]) 2	0	3-1	2-3
350....	3732.54	3732.54	*Co-Fe*	6	1	5-4	8-3

TABLE I—*Continued*

Height of Chromo-sphere	Wave-Lengths		Substance	Intensities			
	Chromo-sphere	Rowland		Rowland	Chromo-sphere	Arc	Spark
km							
350....	3732.90	3732.89	*V*	2	1	3	20
6000....	3734.68	(3734.51)	*Hλ*	...	40	...	...
750....	3735.05	3735.01	*Fe*	40	2	50	10
350....	3735.60	3735.59	*C*	000	0	...	...
1500....	3737.14	{3737.02 3737.28	*Ca-Ni* *Fe*	(2) 8 30	25	20-5 30	50-3 7
400....	3737.81	3737.81	*C*	(2) 0	0	...	...
500....	3738.43	3738.47	*Fe*	(2) 6	0d	2	2
500....	3739.28	3739.33	*Fe, Ni*	(2) 5	1	1, 3	–, 2
500....	3739.89	3739.89	*Fe-Ni*	(3) 6	1d	2-1	2–
300....	3740.49	3740.48	–	0	0	...	...
1500....	3741.78	3741.79	*Ti*	4	15	3	10
300....	3742.38	3742.41	*C*	00	0	...	...
600....	3743.63	3743.67	*Fe-Cr-Gd*	(5) 12	4d	15-7-10	6-6-10
400....	3744.25	3744.25	*Fe*	4	1	2	1
1500....	3745.92	3745.86	*Fe-V*	(2) 14	20d	30-4	9-20
300....	3746.67	3746.65	*Fe-Mn*	(2) 3	0	1-1	1-1
600....	3747.74	3747.69	*Y*	1	4	5	10
750....	3748.39	3748.41	*Fe*	10	8	20	4
6000....	3750.41	(3750.30)	*Hκ*	...	45	...	...
500....	3751.79	3751.80	*Zr*	00	1	3	20
300....	3752.35	3752.37	*C*	00	0	...	...
500....	3753.69	3753.73	*Fe, Ti*	6	2	3, 3	2, 3
300....	3754.33	3754.37	*C*	00	0	...	...
300....	3754.65	3754.66	–	(2) 4	0	...	...
350....	3755.55	3755.59	*Co-C*	1	0	3	4
300....	3756.18	3756.21	*Fe-Er*	3	0	1-3	–1
600....	3757.30	3757.26	*Fe-Cr*	(3) 7	2	2-2	1-2
750....	3757.80	3757.82	*Ti-Cr*	4	10	2-3	6-2
6000....	3759.47	3759.45	*Ti*	12d?	45	10	L20
6000....	3761.47	3761.46	*Ti*	7	40	6	L10
750....	3762.02	3762.01	*Ti*	3	1	1	L4
500....	3762.49	3762.47	*C–*	(2) 2	0	...	...
1000....	3763.93	3763.94	*Fe*	10	4	20	6
800....	{3764.68	3764.69	*C*	(5) 1	1	...	...
800....	{3765.63	3765.69	*Fe*	6	2	4	3
500....	3766.45	3766.47	*C*	1	0	...	...
750....	3766.82	3766.84	*Zr-Fe*	(2) 4	2	4-1	10–
1000....	3767.29	3767.34	*Fe*	8	8	15	5
750....	3768.35	3768.38	*C*	2	2	...	...
6000....	3770.90	(3770.78)	*Hι*	...	50	...	...
400....	3771.80	3771.80	*Ti-C*	2	1	4	3
400....	3772.31	3772.29	*C*	1	0	...	...
300....	3772.71	3772.69	*Ni–*	(2) 3	0	2	1
400....	3773.04	3773.07	*C*	0N	1	...	...
500....	3773.90	3773.90	*C-Fe*	(5) 4	2	...	...
750....	3774.52	3774.47	*Y*	3	10	20	100
600....	3775.68	3775.72	*Ni*	7	3	8	5
600....	3776.16	3776.20	*Ti*	2	3	1	L4
500....	3777.77	{3777.59 3777.98	*Fe* *C*	3 0	2N	1 ...	1 ...

TABLE I—*Continued*

Height of Chromosphere	Wave-Lengths: Chromosphere	Wave-Lengths: Rowland	Substance	Intensities: Rowland	Intensities: Chromosphere	Intensities: Arc	Intensities: Spark
km							
450....	3778.44	3778.42	*Fe-V-Ni*	(3) 7	1	1-1-1	1-3-1
450....	3779.53	3779.57	*Fe-C*	4	2	1–	1–
450....	3780.62	3780.61	*C*	0	1	...	...
450....	3781.80	3781.77	*C-Ce*	1	1	3	3
500....	3782.40	3782.39	*C-Y-Zr-Gd*	(2) 0	1	– – – 4	–5-3-12
750....	3783.61	3783.63	*Ni-C*	(2) 8	5d	8	5
500....	3784.29	3784.28	*C*	(4) 2	1	...	...
500....	3785.29	3785.54	*C*	(4) 2	0	...	...
500....	3785.72				0		
600....	3786.31	3786.31	*Fe, Ti*	4d?	1	2, 3	2, 2
450....	3787.25	3787.30	*C-Fe*	1	0	...	...
750....	3788.06	3788.05	*Fe-Er*	9	2	10-6	4-3
800....	3788.80	3788.84	*Y*	2	8	20	30
450....	3789.14	3789.14	*C*	(2) 1	0	...	...
750....	3790.23	3790.24	*Fe*	5	2	4	2
500....	3790.56	3790.58	*V-C*	(3) 2	1	6–	4–
750....	3790.92	3790.93	*La-C*	(2) 3	2	8–	50–
500....	3791.50	3791.52	*Zr-C*	1	1	4–	3–
600....	3792.65	3792.64	*C-Fe-Ni*	(6) 8	2N	...	...
500....	3793.48	3793.46	*Cr–*	(2) 2	1	2	2
500....	3793.87	3793.88	*C*	0	1	...	...
500....	3794.45	3794.48	*Fe-V-C*	4	2	2-1-	–3–
900....	3794.90	3794.91	*La*	1	4	10	50
450....	3795.33	3795.15	*Fe*	8	0	10	5
		3795.48	*C*	0		...	...
500....	3795.84	3795.88	*Er-C*	00	1	...	4
600....	3796.39	3796.40	*Zr-Gd-C*	(3) 1	1	–10–	10-10–
6000....	3798.15	(3798.05)	*He*	...	50	...	...
750....	3799.66	3799.69	*Fe-C*	7	3	10	5
450....	3800.20	3800.21	*C*	0	1	...	...
500....	3801.51	3801.54	*C*	(3) 2	2d	...	...
450....	3802.42	3802.42	*Fe-Nd*	2	1	1-2	1-2
450....	3802.85	3802.91	*C*	(2) 1	1	...	...
500....	3803.14	3803.18	*C*	(2) 2	2	...	...
500....	3803.56	3803.62	*V*	0	1	4	3
600....	3804.14	3804.15	*C-Fe*	3	2	–1	...
600....	3804.79	3804.79	*C*	(2) 2	2	...	...
750....	3805.46	3805.49	*Fe-Ni-C*	6	2N	4-5-	1-3-
600....	3806.29	3806.33	*Fe-C*	2	1	1	1
500....	3807.45	3807.49	*Ni-V-Fe*	(2) 12	2	8-3-4	7-2-3
450....	3807.82	3807.83	*C*	00	1	...	...
450....	3808.23	3808.27	*C*	1	2N	...	...
450....	3809.25	3809.23	*C*	(2) 1	1	...	...
450....	3809.84	3809.86	*C*	(2) 1	1	...	...
500....	3810.98	3810.97	*Fe-C*	(2) 4	2	1	1
450....	3811.54	3811.48	*C*	(2) 2	1	...	...
500....	3812.14	3812.16	*C*	(2) 1	1	...	...
700....	3813.24	3813.18	*Fe-C*	(3) 7	8N	10–	4–
600....	3813.63	3813.64	*Ti-V-Fe-C*	(3) 4	2	2-10-1-	L4-3-1-
400....	3814.20	3814.21	*Gd*	(2) 1	0	10	6

TABLE I—*Continued*

Height of Chromosphere	Wave-Lengths		Substance	Intensities			
	Chromosphere	Rowland		Rowland	Chromosphere	Arc	Spark
km							
800....	3814.67	3814.70	*Ti-Fe-C*	(2) 8	6	2-2-	L5-1-
900....	3815.96	3815.99	*Fe*	15	10	20	10
400....	3816.47	3816.49	*Fe-Co*	3	0	2-3	1-3
500....	3817.09	3817.06	*Co*	1	1	3	L4
750....	3817.79	3817.79	*Zr-C*	3	2	...	6–
750....	3818.45	3818.43	*Y-V-C*	(2) 2	1	5-4-	10-3-
750....	3819.29	3819.32	*C*	(3) 3	2d	...	...
6000....	3819.77	(3819.75)	*He*	...	4	...	...
1200....	3820.57	3820.59	*Fe*	25	10	50	10
500....	3821.30	3821.33	*Fe*	4	0	3	3
700....	3821.93	3821.96	*Fe-C*	5	2	2	2
500....	3822.46	3822.44	*C*	(2) 1	0	...	...
700....	3822.95	3823.00	*V-C*	1d?	1	2	2
600....	3824.13	3824.13	*Mn-Ce-C*	(3) 2	1	4-2-	4-3-
1000....	3824.60	3824.59	*Fe*	6	8	20	5
700....	3825.46	3825.41	*C*	(2) 1	2	...	...
1000....	3826.00	3826.03	*Fe*	20	8	20	5
500....	3826.37	3826.39	*C*	(2) 1	1	...	...
500....	3826.74	3826.76	–	1N	0	...	...
800....	3827.45	3827.46	*C–*	(2) 2	1	...	...
800....	3827.93	3827.98	*Fe*	8	5	20	7
6000....	3829.49	3829.50	*Mg*	10	20	30	200
800....	3830.71	3830.74	*Er-C*	0	3	10	6
800....	3831.20	3831.17	*C*	3d	3	...	...
6000....	3832.48	3832.45	*Mg*	15	30	50	300
500....	3833.25	3833.22	*C–*	1	1	...	...
750....	3833.87	3833.83	*C*	(3) 1	2	...	...
7000....	3835.69	(3835.53)	*Hη*	...	55	...	...
750....	3836.22	3836.23	*Ti*	2	1	2	L4
1500....	3836.83	3836.66	*C*	2	4	...	...
		3836.90	*Zr*	1		...	20
7000....	3838.44	3838.44	*Mg*	25	40	100	500
500....	3839.28	3839.28	*C*	1	1	...	...
600....	3839.75	3839.81	*Fe-Mn-C*	(4) 5	2	–2–	L3-3-
500....	3840.08	3840.11	*C*	(2) 1	1	...	...
2000....	3840.58	3840.58	*Fe-C*	8	5	15	4
800....	3840.88	3840.89	*V, La*	1	1	4, 3	2, 5
2000....	3841.21	3841.20	*Fe-Mn*	10	5	15-5	5-6
700....	3842.02	3842.04	*Co-C*	(4) 6	2	8–	10–
800....	3843.27	3843.24	*Zr-Fe-C*	(4) 10	3d	–3	L8-2
500....	3844.14	3844.14	*Mn-C*	2	1	3–	4–
600....	3844.43	3844.41	*C-V*	(2) 4	2	–4	–3
600....	3845.28	3845.29	*C-Fe*	(3) 5	1	–1	–1
800....	3845.58	3845.61	*Co-C*	8d?	3	20	30
600....	3846.40	3846.36	*Fe-C*	(3) 5	1	1–	L2–
750....	3846.93	3846.92	*Fe-C*	(4) 8	2	2–	2–
750....	3848.06	3848.03	*C*	(3) 3	2	...	...
500....	3849.07	3849.10	*La-C*	(2) 4	1	5–	10–
500....	3849.59	3849.59	*Ni-Zr*	(2) 2	1	–3	L3-3
800....	3850.07	3850.12	*Fe*	10	4	8	4
700....	3850.76	3850.78	*C*	0	1	...	...

TABLE I—*Continued*

Height of Chromo-sphere	Wave-Lengths		Substance	Intensities			
	Chromo-sphere	Rowland		Rowland	Chromo-sphere	Arc	Spark
km							
700....	3851.36	3851.43	*C*	2Nd?	1	...	...
600....	3851.74	3851.74	*C*	(3) 1	1	...	...
800....	3852.64	3852.61	*Fe-Gd-C*	(3) 7	2	2-10-	2-8-
750....	3853.53	3853.52	*C*	(2) 3	2	...	...
750....	3854.15	3854.12	*C*	(2) 1	1	...	...
800....	3854.59	3854.61	*C-Ce*	(2) 4	3	-3	-3
800....	3854.95	3854.99	*C**	1	3	...	...
750....	3855.72	3855.75	*C-Fe*	(2) 5	2	...	...
6000....	3856.40	3856.46	*Fe-Si*	(2) 9	10	15-	5-5
750....	3856.98	3856.91	*C*	(2) 3	1	...	...
750....	3858.18	3858.22	*Ni-Cr-C*	(2) 13	2	20-3-	8-2-
750....	3858.86	3858.82	*C*	2N	2	...	...
6000....	3860.01	3860.05	*Fe-C*	20	20	20	6
750....	3860.74	3860.77	*C-Ni*	3N	1	...	...
750....	3861.62	3861.66	*C*†	(4) 8	3N	...	...
750....	3862.63	3862.63	*C*	2	2	...	...
750....	3863.56	3863.53	*C-Nd*	3N	2	-10	-8
750....	3864.50	3864.48	*C*	(2) 4	1	...	...
600....	3865.01	3865.00	*V*	3Nd?	1	5	3
900....	3865.26	3865.28	*C*	3	2	...	...
900....	3865.65	3865.67	*Fe-Cr*	7	2	8-1	4-L7
750....	3866.14	3866.12	...	3Nd?	1	...	...
900....	3866.93	3866.96	*C-V*	2	1	-2	-L3
750....	3867.34	3867.36	*Fe-C*	3	1	2-	2-
750....	3867.76	3867.76	*C-V*	1	2	-1	-2
500....	3868.08	3868.06	*Fe-C*	2	1	...	1-
500....	3868.52	3868.54	*C-Ti*	1	1	-4	-1
500....	3868.89	3868.87	*C*	1	1	...	...
500....	3869.27	3869.30	*C*	1	1	...	...
500....	3869.65	3869.69	*Fe-C*	3	2	1-	1-
500....	3870.03	3870.05	*C-Co*	1N	1	...	...
750....	3871.23	3871.24	*C*	(4) 3	2	...	...
750....	3871.51	3871.53	*C*‡	2d?	4	...	...
500....	3871.94	3871.96	*Fe, La*	2	1	2, 6	L4, 20
700....	3872.45	3872.40	*C*	1N	1	...	...
700....	3872.87	3872.86	*C*	1N	1	...	...
900....	3873.19	3873.18	*C-Co*	(3) 6	2	-10	-15
900....	3873.69	3873.71	*C*	1	1	...	...
900....	3874.04	3874.00	*Co-Fe-C*	(2) 8	2	10-2-	15-2-
500....	3874.89	3874.89	*C-*	(2) 3	1	...	...
500....	3875.33	3875.32	*Ti-V-C*	(2) 4	1	5-5-	2-2-
600....	3875.92	3875.92	*C-Nd*	2	2	...	-8
500....	3876.49	3876.50	*C*	(2) 1	1	...	...
600....	3877.06	3877.05	*Co-C*	(2) 8	1	5-	5-
500....	3877.45	3877.48	*C*	1	0	...	...
1200....	3878.79	3878.77	*Fe-V-Co*	(3) 11	15	15-1-	5-L10-L2
600....	3879.73	3879.72	*C-Nd*	1	1	-4	-3

* Fourth edge of cyanogen band.

† Third edge of cyanogen band.

‡ Second edge of cyanogen band.

TABLE I—*Continued*

Height of Chromo-sphere	Wave-Lengths		Substance	Intensities			
	Chromo-sphere	Rowland		Rowland	Chromo-sphere	Arc	Spark
km							
600....	3880.33	3880.31	*C*	(5) 3	2	...	...
600....	3880.82	3880.82	*C*	1	1	...	...
600....	3881.39	3881.36	*C*	(5) 5	2	...	...
700....	3882.05	3882.01	*C-Co*	2	1	...	...
750....	3882.39	3882.44	*C*	2	2	...	...
750....	3882.64	3882.65	*C*	1	3	...	...
900....	3883.43	3883.46	*C**	(2) 3	5	...	...
500....	3883.81	3883.78	*Cr*	0	1	...	1
500....	3884.46	3884.50	*Fe–*	(2) 3	1	1	1
500....	3885.24	3885.29	*Fe*	2	0	...	...
1600....	3886.46	3886.43	*Fe-La*	15	15	20-5	5-15
600....	3887.16	3887.20	*Fe*	7	2	10	3
8500....	3889.47	(3889.20)	H_ζ	...	60	...	...
500....	3890.55	3890.54	*Zr*	2	1	10	4
800....	3890.99	3890.99	*Fe*	3	2	1	1
600....	3891.55	3891.50	*Zr-V-Nd*	(3) 2	1	10-4-3	3-2-3
600....	3892.07	3892.04	*Ba-Fe*	(2) 5	2	50–	500-1
500....	3892.70	3892.70	*Mn*	2	1	1	1
800....	3893.16	3893.10	*V-Fe*	(3) 4	1	4-1	2-1
600....	3893.52	3893.54	*Fe*	4	1	2	2
1000....	3894.26	3894.21	*Co-Cr-*	(2) 8	2	15-3	30-3
500....	3894.65	3894.63	–	1N	0	...	...
500....	3895.20	3895.22	*Co-Ce-Ti*	(3) 6	1	4-3-4	5-2-2
1200....	3895.82	3895.80	*Fe*	7	4	10	3
650....	3896.34	3896.31	*Er-V*	(2) 0	1	15-3	6-3
500....	3896.84	3896.84	*Zr-Ce*	(2) 1	0	3-3	2-3
800....	3897.89	3897.85	*Fe-Zr*	(4) 6	2	3-2	3-2
500....	3898.52	3898.53	*Mn*	2	1	1	2
1000....	3899.23	3899.21	*V-Fe*	(3) 5	3	3-1	L6-1
1000....	3899.84	3899.85	*Fe*	8	3	10	4
1600....	3900.71	3900.68	*Ti*	5	10	5	L50
600....	3901.86	3901.90	*Nd–*	(2) 5	2	5	5
900....	3902.90	3902.89	*Fe-V-Er-Gd*	(4) 16	3d	10-4-10-5	5-2-5-4
1000....	3903.33	3903.37	*V-Cr*	(2) 3	4	4-2	L6-3
700....	3903.95	3904.02	*Fe-Er-*	(2) 8	1	–2	1-3
600....	3904.91	3904.93	*Ti*	3	1	10	5
500....	3905.27	3905.33	–	2	0	...	...
800....	3905.67	3905.66	*Si, Cr*	12	3	15, –	5, L6
600....	3906.03	3906.04	*Nd-Fe*	3	1	4–	4–
750....	3906.62	3906.63	*Fe*	10	2	8	3
500....	3906.86	3906.89	*V*	4	2	3	2
500....	3907.13	3907.10	*Ce*	1	1	2	1
750....	3907.59	3907.62	*Sc*	3d?	2	30	6
600....	3908.05	3908.08	*Fe-Nd*	5	2	1-4	1-3
600....	3908.63	3908.61	*V-Er*	(2) 1	2	2-2	1-2
500....	3909.79	3909.80	*Fe-V*	4	1	1-2	1-2
500....	3910.36	3910.08	*Ba-Co*	3Nd?	1	50-5	10-4
		3910.47	–	2		...	...
500....	3910.82	3910.88	*Fe-V*	(2) 6	1	1-2	1-2

* Head of cyanogen band.

TABLE I—*Continued*

Height of Chromosphere	Wave-Lengths: Chromosphere	Wave-Lengths: Rowland	Substance	Intensities: Rowland	Intensities: Chromosphere	Intensities: Arc	Intensities: Spark
km							
500...	3911.29	3911.32	*Nd*	0	1	8	8
750...	{3911.98	{3911.96	*Sc*	2	1	30	6
750...	{3912.32	{3912.34	*V-Nd*	0	2	4-3	2-3
2000...	3913.69	3913.61	*Ti*	5d?	20	5	L20
750...	3914.60	3914.57	*V-Zr*	1	4	5-	L8-4
500...	3915.47	3915.49	*Fe, Cr*	(2) 2	1	...	...
800...	3916.10	3916.12	*Zr-La*	(2) 1	3	1-5	10-10
750...	3916.67	3916.68	*V-Cr-Fe-Gd*	(3) 10	2	2-3-1-10	L8-2-2-8
500...	3917.39	3917.32	*Fe*	5	0	3	2
750...	{3918.33	{3918.31	*Ce-Mn*	(2) 1	2	3-2	3-3
600...	{3919.03	{3919.04	*Fe-Cr*	(3) 11	1	3-8	2-5
500...	3919.96	3919.96	*Ce-Cr*	0	0	3-1	3-
1000...	3920.39	3920.41	*Fe*	10	6	10	4
600...	3921.25	3921.19	*Cr*	3	1	5	3
600...	3921.73	3921.75	*La-Ti-Zr-Ce*	(3) 9	1	5-5-5-3	10-2-3-3
500...	3922.60	3922.56	*V*	1	1	5	3
1200...	3923.06	3923.05	*Fe*	12d	8	10	15
400...	3924.22	3924.21	*Mn*	1	1	2	2
500...	3925.01	3925.01	*Ti, V*	(2) 8	1	8, 9	3, 5
500...	3925.75	3925.79	*Fe*	5	1	2	1
600...	3926.12	3926.12	*Fe-*	(2) 7	1	2-	1-
500...	3926.99	3927.01	*Cr-*	(3) 1	1	...	...
1000...	3928.10	3928.08	*Fe-V*	8	10	15-4	4-3
500...	3929.30	3929.31	*La-Fe*	(2) 4	1	6-	15-
1000...	3930.39	3930.45	*Fe*	8	8	15	4
500...	3931.29	3931.27	*V-Ce-Fe*	(3) 2	1	4-3-1	3-2-
500...	3931.87	....	...	...	1	...	...
14000...	3934.10	3933.82K	*Ca*	1000	100	500	1000
750...	3935.03	(3934.98)	*Zr-Nd-Gd*	...	1	1-4-6	4-3-2
750...	3936.38	(3936.34)	*Zr-La*	...	1	-2	3-3
900...	3938.49	3938.51	*Cr*	(2) 6	6?*	2	1-
600...	3939.57	....	...	...	1	...	...
600...	3940.31	....	...	...	1	...	...
600...	3941.01	3941.02	*Fe, Co*	5	1	2, 5	1-4
600...	3941.44	3941.42	*Fe, V*	3	1	1, 2	-, 2
600...	{3942.12	{3942.49 group	} *Ce-V-Zr*	(6) 7	1	8-2-1	9-2-4
600...	{3942.89						
2000...	3944.17	3944.16	*Al*	15	15	800	15
600...	3944.85	3944.86	*Y-Dy*	(2) 3	3	-10	L1-10
600...	3945.33	3945.36	*Co-Fe*	(3) 7	3	6-1	5-1
400...	3946.57	3946.60	–	(4) 2	1	...	...
600...	3947.88	3947.92	*Ti*	2	2	10	3
600...	3948.27	3948.25	*Fe-Er-Sa*	5	1	2-3-3	1-1-3
600...	3948.80	3948.82	*Ti*	4	2	12	4
750...	3949.21	3949.20	*La*	1	4	20	50
500...	3950.10	3950.10	*Fe*	5	2	3	2
750...	3950.47	3950.50	*Y*	2	4	20	L20
500...	3951.34	3951.32	*Nd-Fe*	5	2	10-2	8-2

* Coincides with ghost of K.

TABLE I—*Continued*

Height of Chromosphere	Wave-Lengths		Substance	Intensities			
	Chromosphere	Rowland		Rowland	Chromosphere	Arc	Spark
km							
600...	3952.11	3952.10	*V*	2	2	2	L15
600...	{3952.80	{3952.80	*Ce-Fe*	(2) 7	2	8-2	7-2
600...	{3953.17	{3953.16	*Co-Mn*	(4) 10	2	8-2	6-3
400...	3954.67	3954.68	*Ni-Mn*	2	0	-1	1-
400...	3955.51	3955.48	*Fe*	5	0	1	...
800...	3956.53	3956.54	*Ti-Ce-Fe*	(2) 8	6d	15-3-2	4-3-2
400...	3957.19	3957.18	*Ca-Fe*	7d?	0	10-1	2-1
800...	3958.37	3958.36	*Zr, Ti*	5	8	3, 15	L20, 5
550...	3959.62	3959.63	*Gd-*	(2) 0	1N	6	6
400...	3960.47	3960.42	*Fe*	4	0	...	...
1500...	3961.65	3961.67	*Al*	20	20	1000	100
600...	3964.63	3964.65	*Ti-Fe*	(2) 5	1	8-1	3-
1000...	3964.86	(3964.88)	*He*	...	4	...	...
500...	3965.65	3965.66	–	2	0	...	...
500...	3966.72	3966.76	*Fe-Zr*	(3) 6	0	3-5	2-3
14000...	3968.92	3968.62H	*Ca*	700	80	300	500
8500...	3970.48	3970.18H_ϵ	H_ϵ	5	60	...	...
400...	3971.70	....	...	...	0	...	...
700...	3972.03	3972.05	*Eu-Gd*	(2) 1	1	50-4	50-3
700...	3972.41	3972.40	*Ni-Nd*	(3) 4	2	-2	1-2
750...	3973.74	3973.70	*Zr*	3	5	10	3
500...	3974.70	3974.76	*Co-Er-Ni*	(4) 13	1	4-15-2	4-5-
500...	3976.85	3976.84	*Cr*	3	2	6	8
500...	3977.33	3977.34	*Co*	0	0	...	L3
700...	3977.91	3977.89	*Fe-V*	6	2	3-	2-4
500...	3978.74	3978.73	*Co, Ce*	(2) 5	0	3, 3	3, 3
700...	3979.63	3979.66	*Cr-Nd-Co*	4	2	-5-4	L5-4-4
400...	3981.11	3981.12	*Ce-Nd*	1	0	2-1	3-3
700...	3981.95	3981.92	*Ti*	4	4	15	3
800...	3982.69	3982.70	*Y-Ti*	(2) 5	6	20-8	L20-3
400...	3983.31	3983.34	*Ce-Er*	2N	0	2-2	3-3
600...	{3983.81	{3983.81	*Dy*	00	1	10	4
650...	{3984.20	{3984.17	*Fe-Mn*	(2) 6	2	2-1	2-1
400...	3984.78	3984.81	*Zr-Ce*	2	0	3-3	3-3
400...	3985.50	3985.52	*Fe-Mn*	(2) 4	1	1-2	1-3
500...	3986.32	3986.32	*Fe-Nd*	3	2	1-4	1-4
500...	3986.87	3986.90	*Mn-Zr*	6	2	2-1	4-1
500...	3987.29	3987.24	*Co-Mn*	(3) 5	1	1-2	L3-4
600...	3987.70	3987.75	*Ti*	2	1	...	L1
500...	3988.61	3988.66	*La*	0	6	15	30
400...	3989.23	3989.23	–	2	0	...	...
600...	{3989.91	{3989.91	*Ti*	4	3	20	4
600...	{3990.26	{3990.24	*Cr-Nd-Co*	(3) 2	2	3-8-3	3-6-3
700...	3991.30	3991.33	*Zr-Cr*	3	5	3-5	20-4
500...	3991.79	3991.80	*Co-Cr*	(2) 3	2	3-3	8-2
400...	3992.43	3992.40	–	2	1	...	...
400...	3993.00	3992.97	*V-Cr*	3d?	1	10-3	6-3
400...	3993.27	3993.25	*Fe*	2	0	...	...
400...	3993.94	3993.93	*Ti-Ce*	0	1	1-3	-4
500...	3994.82	3994.83	*Nd*	2	2	8	5
550...	3995.45	3995.46	*Co*	5	3	20	20

TABLE I—*Continued*

Height of Chromosphere	Wave-Lengths: Chromosphere	Wave-Lengths: Rowland	Substance	Intensities: Rowland	Intensities: Chromosphere	Intensities: Arc	Intensities: Spark
km							
550....	3995.91	3995.90	*La*	1Nd?	3	10	5
350....	3996.71	3996.68	*Sc*	00	0	15	3
500....	3997.10	3997.12	*Fe*	2	1	...	1
600....	3997.55	3997.55	*Fe*	4	2	4	3
500....	3998.11	3998.13	*Co-Fe*	(2) 8	2d	10-2	10-2
800....	3998.88	3998.85	*Ti-Zr*	(2) 5	4	20-4	4-20
800....	3999.35	3999.39	*V-Ce*	0	8	-5	L3-6
550....	4000.52	4000.51	*Fe-Y-Dy*	(2) 4	3d	-1-20	-1-15
500....	4001.29	4001.32	*Mn-Gd*	3	1	1-3	1-2
500....	4001.79	4001.81	*Fe-Ce*	3	2	1-4	1-4
400....	4002.48	4002.44	*Fe-Ti*	(4) 3	0	...	...
400....	4003.05	4003.08	*V*	2	1	1	5
500....	4003.95	4003.91	*Ti-Ce*	3	2	2-3	2-4
400....	4004.58	4004.64	–	(2) 0	0	...	...
500....	4005.09	4005.07	*Gd-Fe*	(3) 3	1	3-	3-
800....	4005.42	4005.41	*Fe*	7	6	15	6
800....	4005.88	4005.86	*V*	3	6	2	L20
500....	4006.43	4006.46	*Fe*	2	1	1	1
500....	4006.88	4006.83	*Fe-*	(2) 5	2	1	1
400....	4007.12	4007.14	*V-Mn*	1	0	1-3	-1
600....	4007.48	4007.43	*Fe*	3	2	1	1
350....	4008.14	4008.14	*Ti-Er*	(2) 1	0	2-10	1-4
600....	4008.95	4009.05	*Ti-Gd-Pr*	(3) 6	2	10-3-15	4-3-8
1000....	4009.46	(4009.42)	*He*	...	0	...	...
800....	4009.87	4009.86	*Fe-V*	3	2	2-2	2-1
500....	4010.58	4010.63	*Ce-*	(2) 4	0	1-	2-
350....	4011.33	4011.31	*Fe*	(3) 7	2d	...	...
800....	4012.55	4012.56	*Ti-Cr*	(2) 4	15	1-2	L5-L6
400....	4012.93	4012.94	*Ti-Nd*	00	0	1-3	-2
600....	4013.90	4013.90	*Ti-Fe*	(2) 8	1d	3-1	1-
800....	4014.67	4014.68	*Sc-Fe*	5d?	3	6-2	8-2
400....	4015.08	4015.09	*Ce*	0Nd?	0	3	4
500....	4015.69	4015.71	*Ni-Er-La*	(2) 4	1d	-6-3	L2-3-1
400....	4017.33	4017.31	*V-Fe*	4	1	-1	L3-1
400....	4017.95	4017.92	*Ti*	0	0	4	2
		4018.25	*Mn*	7		10	8
500....	4018.42	4018.42	*Fe*	3	2	1	1
500....	4019.18	4019.20	*V-Ce*	1	1	1-1	3-2
400....	4019.46	4019.45	*Co*	0	0	2	2
400....	4020.20	4020.23	*Mn*	1	0	1	1
500....	4020.58	4020.55	*Sc*	1	2	20	8
500....	4021.02	4021.06	*Co-Nd*	3	2	8-4	5-4
600....	4021.55	4021.49	*Nd*	0	2	4	4
700....	4022.05	4022.02	*Ti-Fe*	5	4	4-2	2-2
350....	4022.47	4022.50	*Gd-Ce-Fe*	(2) 1	0	3-2-	3-2-
500....	4023.16	4023.16	*Nd*	0	1	5	5
750....	4023.56	4023.53	*V-Co*	3	4	2-2	L20-L3
750....	4023.80	4023.83	*Sc*	2	2	30	8
500....	4024.20	4024.21	*Zr-Fe*	(2) 3	0	5-	3-
750....	4024.75	4024.73	*Ti*	3	3	10	3
750....	4025.28	4025.29	*Ti-Ce*	3	3	1-2	L3-2

TABLE I—*Continued*

Height of Chromosphere	Wave-Lengths: Chromosphere	Wave-Lengths: Rowland	Substance	Intensities: Rowland	Intensities: Chromosphere	Intensities: Arc	Intensities: Spark
km							
6000....	4026.47	(4026.34)	*He*	...	20	...	...
400....	4027.35	4027.40	*Zr*	00	0	5	3
500....	4027.81	4027.82	*Ce*	1	1	1	3
450....	4028.10	4028.09	–	0	0	...	...
750....	4028.50	4028.50	*Ti-Ce*	4	6	1-4	L6-4
350....	4029.12	4029.14	*Zr*	000	0	4	2
500....	4029.74	4029.80	*Zr-Fe*	5	2	4-1	2-1
700....	4030.62	4030.65	*Ti-Nd*	5	4	8-4	2-4
750....	4030.93	4030.92	*Mn*	9	12	100	20
500....	4031.40	4031.43	*V-Ce*	(2) 2	1	2-4	2-4
600....	4031.83	4031.86	*La*	2	2	5	20
		4031.94	*Nd-Mn*	2		8-2	10-3
400....	4032.14	4032.12	*Fe*	2	0	1	1
750....	4032.75	4032.73	*Fe-Dy*	(2) 6	2	1-4	1-4
750....	4033.21	4033.22	*Mn*	8d?	9	100	20
750....	4034.61	4034.64	*Mn-Fe*	6d	8	50-2	10–
750....	4035.70	4035.75	*V-Co*	2	3	2-8	L20-3
		4035.88	*Mn*	4		5	8
750....	4036.08	4036.05	*Zr, Ti*	(2) 1	3	5, 3	3, 2
400....	4036.57	4036.52	–	0	0	...	...
350....	4036.96	4036.92	*V*	1	0	1	4
400....	4037.46	4037.45	*Gd*	00	1	10	6
350....	4038.70	4038.74	*Fe, Mn–*	(4) 4	0	...	...
350....	4039.75	4039.73	*V-Gd*	0	0	1-3	3-2
350....	4040.16	4040.19	*V-Fe*	(2) 3	0	1-1	...
600....	4040.96	4040.94	*Ce-Nd*	1d?	5	6-5	8-4
600....	4041.52	4041.52	*Mn-Fe-Zr*	(3) 9	2d	20-1-2	10-1-1
300....	4042.20	....	...	...	0	...	...
600....	4042.76	4042.74	*Ce-V*	0	2	5-3	5-3
600....	4043.01	4043.05	*La*	0	4	5	20
500....	4043.86	4043.84	*Ti*	0	1	1	1
500....	4044.12	4044.09	*Fe–*	(2) 5	1	1	1
500....	4044.78	4044.77	*Zr-Fe*	3	1d?	5-1	3-1
500....	4045.51	4045.54	*Co-Er*	5	2	8-3	5-2
1000....	4045.98	4045.98	*Fe*	30	15	50	15
400....	4046.56	4046.55	*V-Ce*	(2) 1	0	–3	4-4
600....	4047.12	4047.17	–	00N	1	...	...
300....	4047.48	4047.46	*V-Fe*	2	0	1–	1–
400....	4047.82	4047.82	*Y*	0N	0	8	4
400....	4048.23	4048.22	–	1N	1	...	...
600....	4048.88	4048.88	*Zr-Mn-Fe*	6d	5d	4-8-2	10-7-L4
500....	4049.60	4049.59	*Fe-Gd-Cr*	(3) 4	1	–8–	–4–
500....	4049.95	4050.02	*Gd*	00	0	10	6
500....	4050.46	4050.48	*Zr*	0	2	2	8
300....	4051.05	4051.10	–	00	0	...	...
500....	4052.24	4052.22	*Cr, Fe*	(2) 5	1	–, –	L3, –
500....	4052.62	4052.63	*Mn-Fe*	(2) 5	1	2–	3–
700....	4053.48	4053.42	*V-Gd*	2	1	2-5	2-5
750....	4053.98	4053.98	*Ti-Fe*	3	3	1–	L5–
500....	4054.67	4054.71	*Sc*	00N	1	10	3
500....	4054.97	4055.00	*Fe*	(2) 5	2	2	2
500....	4055.22	4055.19	*Ti-Zr*	3	1	4-5	3-3

TABLE I—*Continued*

Height of Chromosphere	Wave-Lengths		Substance	Intensities			
	Chromosphere	Rowland		Rowland	Chromosphere	Arc	Spark
km							
600....	4055.82	{4055.70 4055.86	*Mn-Fe* *Zr*	6 00	} 1	{ 4-2 4	8-L3 3
400....	{4056.30	{4056.28	*V, Cr*	(²) 1	0	1, 1	1, 2
400....	4056.69	4056.65	*Sc-Zr*	(²) 1	0	3-1	-1
400....	4057.24	4057.22	*V*	0	1	5	3
500....	4057.63	4057.67	–	7	2	...	...
450....	4058.32	4058.37	*Co-Ti-Gd*	4	1	4-2-4	3-2-3
500....	4059.07	4059.08	*Mn*	3	2	4	6
450....	4059.58	4059.54	*Mn-Gd*	1Nd?	0	3-2	2-3
450....	4059.88	4059.87	*Er-Fe*	2	1	10–	4–
450....	4060.47	4060.42	*Ti*	1	1	5	3
700....	4061.20	4061.24	*Nd*	3	3	10	10
400....	4062.28	4062.28	*Ce-*	(²) 0	0	2–	4–
600....	{4062.65	4062.63	*Fe-Gd*	(²) 5	2	2-4	2-6
400....	4062.99	4063.00	*Cu-*	(²) 0	0	100–	10–
900....	4063.70	4063.70	*Fe*	(²) 24	12	30	10
400....	4064.77	4064.73	–	00	1	...	...
500....	4065.46	4065.42	*V-Ti*	(²) 5	2	2-4	L6-3
500....	4066.64	4066.63	*Co-Fe*	(²) 4	2	5-1	5–
500....	4067.21	4067.25	*Ni-Fe*	(²) 8	4	–4	L5-2
500....	4067.57	4067.56	*La*	000	0	4	8
450....	4068.15	4068.14	*Fe-Mn*	6	1	2-2	1-2
450....	4068.77	4068.79	*Co-Ce*	(²) 1	2	4-5	5-5
450....	4069.34	4069.29	*Nd-Ti*	(²) 2	2	4-1	4-1
400....	4069.75	4069.76	–	1	0	...	...
400....	4070.44	4070.43	*Mn-Gd*	3	1	4-10	3-5
400....	4071.05	4071.00	*Cr-Fe*	(³) 5	1d	–1	L4-1
900....	4071.90	4071.91	*Fe*	15	10	20	8
400....	4072.50	4072.53	*Fe-V*	(³) 3	0	...	...
400....	4073.27	4073.29	*Gd*	0	0	4	4
500....	{4073.55	{4073.64	*Ce*	0	1	3	4
500....	4073.89	4073.92	*Gd-Fe*	4	3	10-1	8-1
350....	4074.45	4074.49	*Ti-Nd*	0N	0	–2	1-1
500....	4075.12	4075.07	*Nd-Fe*	(²) 5	2d	6-1	4-1
400....	4075.82	4075.86	*Ce*	0	1	3	3
500....	4076.22	4076.17	*Cr-Ce-Fe*	(²) 4	2	4-3-	1-3-
400....	4076.66	4076.64	*Fe-Zr*	2	0	3-3	2-1
6000....	4077.98	4077.88	*Sr*	8	40	1000	L1000
500....	4078.64	4078.63	*Ti*	3	3	8	4
500....	{4079.26	{4079.33	*Fe-La*	2	1	–2	–1
600....	4079.81	4079.78	*Mn-Fe*	(²) 6	2	3–	5–
500....	4080.47	4080.37	*Fe, Nd*	3	1	1, 3	–, 2
500....	4081.36	4081.38	*Zr-Ce-Er*	0	2	10-4-8	5-4-3
350....	{4082.37	{4082.31	*Fe-Zr*	2	0	–2	–2
400....	4082.58	4082.59	*Sc-Cr-Ti*	3	1	15-5-	3-3-L2
350....	4082.79	4082.75	*Co*	0	0	2	2
400....	{4083.18	{4083.14	*Mn-Ce*	(²) 5	0	4-3	6-5
500....	4083.62						
400....	4083.97	4083.92	*Y-Fe*	1	1	8–	3–
400....	4084.24	4084.31	*Zr-*	(²) 1	0	2–	2–
400....	4084.64	4084.65	*Fe*	5	1	2	1

TABLE I—*Continued*

Height of Chromo-sphere	Wave-Lengths		Substance	Intensities			
	Chromo-sphere	Rowland		Rowland	Chromo-sphere	Arc	Spark
km							
500....	4085.32	4085.32	*Fe-Ce*	(^{3}) 9	3	3-3	1-3
450....	4086.44	4086.47	*Co*	3d?	2	10	8
500....	4086.79	4086.86	*La*	1	4	10	20
400....	4087.22	4087.25	*Sc-Fe*	3	1	3-1	...
450....	4088.71	4088.71	*Nd-Ce*	3	2	2-1	1−
400....	4089.37	4089.37	*Fe*	3	1	...	...
400....	4090.05	4090.11	*Mn*	0Nd?	1	2	2
500....	4090.72	4090.71	*V-Zr*	(^{2}) 1	2	10-3	10-4
400....	4091.12	4091.11	*Ce*	3	1	2	2
400....	4091.69	4091.71	*Fe*	3	1	...	...
500....	4092.56	4092.55	*Co-Mn*	3	3	8-1	10-2
500....	4092.87	4092.82	*V-Ca*	3d?	3	15-4	3-1
400....	4094.51	4094.57	*Gd*	2N	0	4	3
400....	4095.05	4095.09	*Ca*	4	1	6	2
500....	4096.17	4096.20	*Fe-Nd*	(^{2}) 5	2	−3	1-3
500....	4096.94*	....	...	...	2	...	...
500....	4097.96	4097.96	−	(^{3}) 1	0	...	...
500....	4098.33	4098.34	*Fe-Nd*	5	3	1-3	1-3
500....	4098.98	4098.95	*Gd-Ca*	000	2	15-10	6-2
500....	4099.95	4099.94	*V*	2	1	20	10
8000....	4102.00	4102.00	H_δ	40N	70	...	...
500....	4103.10	4103.10	*Si, Mn*	5	1	1, 1	1, 2
400....	4103.65	4103.62	−	(^{2}) 1	0	...	...
450....	4104.27	4104.29	*Fe*	5	2	1	1
400....	4104.65	4104.62	*Co, V*	0	0	2, 3	1, 3
450....	4105.21	4105.24	*V-La*	(^{2}) 3	3	10-3	5-1
450....	4106.49	4106.50	*Fe*	(^{2}) 4	2d	...	...
450....	4107.64*	4107.65	*Ce-Fe-Zr*	5	2	3-3-3	4-2-2
400....	4108.69	4108.69	*Nh, Er*	2	0	10, 2	5, 1
600....	4109.37	4109.31	*Nd*	(^{2}) 4	3	13	14
600....	4109.88	4109.90	*V*	2	3	15	10
500....	4110.63	4110.69	*Co*	4	2	10	10
450....	4111.62	(4111.57)	*Ce, Gd*	...	1	3, 4	3, 4
450....	4111.97	4111.94	*V*	4	2	30	4
400....	4112.45	4112.48	*V-Fe*	2	0	2−	2−
400....	4112.89	4112.87	*Ti*	1	0	5	2
400....	4113.24	4113.18	*Fe, Mn*	(^{2}) 4	1	1, 1	−, 2
450....	4114.00	4114.02	*Nd-Sa*	00Nd?	2d	3-3	4-3
450....	4114.73	4114.77	*Fe-V*	(^{2}) 6	3	2-2	1-2
450....	4115.35	4115.33	*V*	3	3	5	6
400....	4116.14	4116.14	*Ni*	0	1	1	1
450....	4116.78	4116.74	*V-Nd*	(^{3}) 2	2d	15-4	5-4
500....	4118.02	4118.01	−	2	1	...	...
600....	4118.85	4118.85	*Co-Fe-V*	(^{3}) 11	5N	10-4-3	20-3-3
350....	4119.53	4119.55	*V-Fe*	1	0	4−	3−
350....	4119.74	4119.75	−	(^{2}) 1	...	...	...
350....	4120.12	4120.08	*Ti*	0	0	1	1
400....	4120.35	4120.37	*Fe*	4	1	1	1
1000....	4120.93	(4120.97)	*He*	...	2	...	...
500....	4121.46	4121.48	*Co*	6d?	3	20	20

* Coincides with ghost of H_δ.

TABLE I—*Continued*

Height of Chromo-sphere	Wave-Lengths: Chromo-sphere	Wave-Lengths: Rowland	Substance	Intensities: Rowland	Intensities: Chromo-sphere	Intensities: Arc	Intensities: Spark
km							
350....	4122.02	4122.05	*Ti, Cr*	(2) 4	1d	3, 2	2, 2
500....	4122.80	4122.82	–	1	3	...	...
650....	4123.45	4123.44	*La-V*	(2) 2	5	10-7	30-5
500....	4123.93	4123.91	*Fe, Ce-Nd*	5	3	1, 4-4	1, 5-4
500....	4124.96	4124.94	*Ce*	0	2	3	4
400....	4125.93	4125.90	*Fe–*	(3) 7	1	...	...
400....	4126.35	4126.34	*Fe*	4	0	1	...
400....	4126.66	4126.67	*Cr*	2	1	3	3
550....	4127.86	4127.86	*Fe-Ce*	(2) 8	5	3-2	1-2
550....	4128.25	4128.25	*V*	6d	5	10	10
550....	4128.91	4128.89	*Nd*	2	0	1	2
400....	4129.41	4129.45	*Ce-Pr*	(2) 5	1	2-4	2-3
550....	4129.88	4129.88	*Eu*	1	5	100	100
450....	4130.83	4130.80	*Ba*	2	2	100	L800
400....	4131.46	4131.51	*Cr*	0	0	1	2
550....	4132.05	4132.10	*V*	2	2	10	10
550....	4132.28	4132.24	*Fe*	10	2	15	4
500....	4133.05	4133.06	*Fe-Sc*	4	1	2-4	2–
500....	4133.93	4133.91	*Fe-Ce*	(3) 5	2d	1-8	–10
400....	4134.49	4134.54	*V-Fe*	(2) 6	2	10-1	10–
500....	4134.84	4134.84	*Fe*	5	5	3	2
500....	4135.56	4135.53	*Nd, Ce*	(2) 1	2d?	8, 3	7, 3
400....	4136.02	4135.97	*Zr-Ce*	(2) 1	1	3-1	2-2
500....	4136.69	4136.68	*Fe*	4	2	...	...
500....	4137.21	4137.16	*Mn-Fe-Gd*	6	3	-2-5	L3-8
500....	4137.79	4137.81	*Ce*	1	4	4	10
400....	4138.31	4138.32	*V-Ce*	(2) 1	0	2-2	2-2
400....	4139.08	4139.01	–	0	1	...	...
350....	4139.57	....	...	0	...	...	...
400....	4140.24	4140.24	*Fe–*	(2) 9	1	1	...
400....	4141.81	4141.81	*La*	0	1	5	10
400....	4142.03	4142.02	*Fe*	4	1	...	...
400....	4142.56	4142.54	*Cr-Ce*	(4) 8	2	–3	–5
400....	4143.28	4143.21	*Er-Pr*	(2) 1	2	10-20	5-10
1000....	4144.05	(4143.92)	*He*	...	6d	...	...
		4144.04	*Fe*	15		15	5
450....	4144.63	4144.67	*Ce-Nd*	0Nd?	2	3-3	3-2
450....	4145.13	4145.15	*Ce*	0	2	4	8
400....	4145.37	4145.36	*Co*	1	0	...	L3
400....	4145.84	4145.84	*Cr-V*	(2) 1	1	–1	L6–
400....	4146.23	4146.22	*Nd-Fe*	3	2	2–	3–
400....	4147.12	4147.14	–	2	0	...	...
400....	4147.69	4147.71	*Fe-Mn*	(3) 7	2	3-2	1-2
400....	4148.98	4148.95	*Mn*	0	1	2	3
600....	4149.37	4149.36	*Zr*	2	8	6	30
400....	4150.03	4150.06	*Ce*	00	2	10	10
400....	4150.40	4150.41	–	4	0	...	...
400....	4150.68	4150.64	*Ti-Co*	(2) 2	1	1–	1–
500....	4151.18	4151.13	*Zr-Ti-Ce*	1	3	3-3-3	6-3-3
500....	4152.23	4152.25	*La, Ce-Fe*	(3) 6	6N	6, 4-	10, 9-
350....	4152.68*	4152.66	*Zr-Sc-C*	(3) 1	0	3-8-	2–

* Sixth edge of second cyanogen band.

TABLE I—*Continued*

Height of Chromo-sphere	Wave-Lengths		Substance	Intensities			
	Chromo-sphere	Rowland		Rowland	Chromo-sphere	Arc	Spark
400....	4153.51	4153.54	*Fe-Sa*	1	0	−4	−3
500....	4154.09	4154.11	*Fe-Cr-*	(3) 7	2d	4-3-	2-3-
500....	4154.67	4154.67	*Fe*	4	3	4	2
500....	4156.30	4156.34	*Zr-Nd-*	(4) 5	8	4-10-	10-10-
500....	4157.00	4156.97	*Fe*	3d?	3	4	2
400....	4158.00	4157.95	*Fe*	5	3	3	1
400....	4158.20	4158.17*	*C*	00	1	...	...
400....	4159.00	4158.96	*Fe*	5	2d?	2	1
350....	4159.40	4159.35	–	5	0	...	...
400....	4160.57	4160.59	*Co-Nd-*	(2) 3	0d	1-3-	L8-4-
400....	4161.23	4161.30	*Zr–*	(2) 4	1	4–	10–
600....	4161.65	4161.68	*Ti*	4	5	...	L3
400....	4162.79	4162.72	*Gd-Ce-*	(2) 2N	2d	4-1	3-2
650....	4163.82	4163.82	*Ti-Cr*	4	10	2-2	L20-4
400....	4164.45	4164.46	*C?*	(2) 1	1	...	...
350....	4164.88	4164.88	*Er-C*	(2) 1	0	2–	1–
400....	4165.33	4165.33	*Sc-C*	00	1	8–	...
500....	4165.73	4165.76	*Ce*	1	2	4	10
400....	4166.16	4166.16	*Ba*	0	0	10	100
400....	{4167.00	4167.01	*Ce*	0	1	3	5
1500....	{4167.60	{4167.44	–	8}	3	10	4
		{4167.74†	*Y-C*	1}			
400....	{4168.09	4168.08	*C-Nd-Dy*	(2) 4	2d	2-2-20	3-3-4
400....	4168.91	4168.95	–	(2) 4	1d	...	...
1500....	4169.20	(4169.13)	*He*	...	0	...	...
400....	{4169.52	....	...	...	2	...	...
400....	{4169.96	4169.93	*Ce*	2	2	5	5
350....	4170.52	4170.51	*Cr-Nd*	(3) 1	0	1-2	2-2
500....	4171.21	4171.21	*Ti*	4	3	3	2
600....	4172.15	4172.07	*Ti*	2	10d?	1	L15
600....	4172.83	4172.86	*Fe–*	(2) 6	1d	2–	1–
600....	4173.64	4173.67	*Ti-Fe*	(2) 6	10	–1	L3-L3
500....	4174.10	4174.12	*Ti-Fe*	(2) 4	1d	–1	L2-1
500....	4175.04	4175.06	*Fe-Cr*	(2) 4	2	3-3	1-3
500....	4175.80	4175.81	*Fe-Nd*	5	3	3-4	2-5
400....	4176.74	4176.74	*Fe-Mn-Ce*	5	1	2-2-2	1-4-3
700....	4177.70	4177.70	*Y-Fe*	3	12	15-2	L50-1
600....	4179.03	4179.02	*Fe*	3	8	...	L3
600....	4179.58	4179.54	*V-Pr*	3d?	3	5-20	3-10
400....	4180.51	4180.56	*C–*	1	1	...	...
400....	4180.98	4180.97‡	*C*	2N	2	...	...
600....	4181.97	4181.95	*Fe–*	(3) 8	3d	4	4
450....	4182.52	4182.55	*Fe*	3	2	1	1
350....	4182.90	4182.92	–	2	0	...	...
400....	4183.54	4183.57	*V-Zr*	(2) 3N	2d	1-3	L10-3
500....	4184.35	4184.32	*Ti-Gd-*	(3) 6	3d	–10	L1-10
500....	4185.05	4185.06	*Fe-Nd-C*	4	3	3-2-	2-4-
350....	4185.87	4185.89	*C–*	(2) 1	1	...	...

* Fifth edge of second cyanogen band.

† Fourth edge of second cyanogen band.

‡ Third edge of second cyanogen band.

TABLE I—*Continued*

Height of Chromo-sphere	Wave-Lengths		Substance	Intensities			
	Chromo-sphere	Rowland		Rowland	Chromo-sphere	Arc	Spark
km							
600....	4186.70	4186.78	*Ce-Zr*	2N	3	10–	10-4
600....	4187.24	4187.20	*Fe*	6	4	8	4
600....	4187.93	4187.91	*Fe-Ti-Ni*	(4) 10	4	10-5-1	4-3-L4
400....	4188.89	4188.89	*Ti-Nd*	4	2N	2-1	1-1
400....	4189.58	....	*C*	...	1	...	...
400....	4190.22	4190.22	*Er-Mn-C*	(2) 1	2	5-2-	4-4-
350....	4190.85	4190.87	*Co-Er-C*	1Nd?	0	5-5-	3-3-
550....	4191.63	4191.68	*Fe*	(2) 9	5d	5	3
350....	4192.20	4192.17	*Cr-C*	0	0	2–	2–
400....	4192.70	4192.73	*–C*	2N	0	...	...
400....	4193.11	4193.07	*C*	00	1	...	...
400....	4193.58	4193.58	*C*	(2) 0	2d	...	...
400....	4194.00	4193.96	*Ce-C*	0	1	2–	3–
350....	4194.60	4194.57	*·C*	(4) 1	1N	...	...
450....	4195.12	4195.06	*Nd-Ce*	(2) 1	2	3-2	3-3
450....	4195.66	4195.67	*Fe-C*	(3) 8	2N	3-	1-
500....	4196.75	4196.70	*La*	2	2	10	10
500....	4197.27	4197.26*	*C*	2	3	...	...
400....	4197.80	4197.81	*C*	00	1	...	...
600....	4198.41	4198.40	*Fe–*	(3) 10	5d	5–	3–
600....	4198.85	4198.80	*Ce-Fe-C*	3	3	10-1-	6–
600....	4199.25	4199.27	*Zr-Fe*	5	5	6-6	5-3
500....	4200.10	4200.15	*Fe-Nd*	2	1	1-1	–2
500....	4200.83	4200.85	*Ti-Fe-C*	(5) 5	3N	2-1-	2–
400....	4201.90	4201.87	*Mn-Ni*	1	0	1-2	2–
600....	4202.29	4202.20	*Fe*	8	6	10	6
400....	4202.59	4202.57	*V-C*	0Nd?	0	2–	3–
500....	4203.15	4203.10	*Ce-Sa*	0N	3	5-10	5-6
400....	4203.75	4203.73	*Cr*	2	0	2	1
500....	4204.14	4204.14	*Fe-La*	(2) 7	2	3-4	2-4
400....	4204.84	4204.88	*Y*	1	0	5	L5
550....	4205.22	4205.21	*V-Eu*	(2) 2	8	1-100	L10-50
450....	4205.70	4205.70	*Nd*	2	1	4	4
400....	{4206.44	{4206.46	–	0	0	...	...
400....	{4206.99	{4207.03	*Fe-Pr*	(3) 7	2d	2-20	2-15
400....	{4207.40	{4207.36	*Fe-C*	(2) 4	1d	1–	1–
350....	4208.30	4208.27	*C*	00	0	...	...
350....	4208.75	4208.77	*Fe*	3	0	1	1
550....	4209.11	4209.14	*Zr*	1	4	4	L20
350....	4209.87	4209.84	*V-Cr-*	(3) 2	0	8-1-	9-1-
500....	4210.53	4210.52	*Fe-Sa*	(2) 7	3d	4-8	3-3
350....	4210.92	4210.86	*Zr-C*	000	0	...	3–
400....	4211.41	4211.46	*Nd-C*	(2) 1	0	4–	5–
500....	4212.04	4212.05	*Zr-C*	2	3	3–	5–
400....	4212.89	4212.84	*Cr-C*	(2) 3N	1	2–	2–
500....	4213.81	4213.81	*Fe-C*	3	3N	1–	1–
350....	4214.22	4214.20	*C*	00	0	...	...
6000....	4215.88	4215.87†	*Sr*	5d?	40	500	L500
400....	4216.32	4216.35	*Fe*	3d?	1	3	1

* Second edge of second cyanogen band.

† Edge of second cyanogen band at 4216.14.

TABLE I—*Continued*

Height of Chromosphere	Wave-Lengths		Substance	Intensities			
	Chromosphere	Rowland		Rowland	Chromosphere	Arc	Spark
km							
500....	4217.28	4217.36	*Gd*	1	2	5	5
500....	4217.70	4217.72	*La-Cr*	5	2	4-3	10-2
400....	4218.52	4218.56	*Zr, Er*	1Nd	1	3, 8	2, 3
400....	4218.84	4218.88	*V*	3N	1	2	2
500....	4219.56	4219.54	*Fe-*	(2) 7	3	3-	3-
450....	4220.48	4220.51	*Fe*	3	2	1	1
450....	4220.78	4220.81	*Y-Sa*	00	2	10-8	1-4
500....	4222.38	4222.38	*Fe*	5	2	4	2
500....	4223.10	4223.11	*Ce-Pr-*	(5) 2	1	10-18	5-15
400....	4223.64	4223.69	–	(2) 2	1	...	...
450....	4224.35	4224.34	*Fe-V*	4	2	3-3	1-2
400....	4224.83	4224.81	*Cr*	(2) 5	1d	...	L4
500....	4225.45	4225.49	*V-Sa-Pr*	000	2	1-10-20	L6-4-15
5000....	4226.90	4226.90	*Ca*	20d?	25	1000	100
400....	4227.88	4227 92	*Zr-V-Ce-Nd*	0	2	10-2-3-3	4-3-4-3
350....	4228.34	(4228.35)	*Nd*	...	0	3	2
350....	4228.84	4228.88	–	1	1	...	...
400....	4229.87	4229.86	*Fe-V-Sa*	(3) 6	3d	1-2-10	-3-4
350....	4230.45	4230.41	*Er*	00Nd?	0	8	3
500....	4231.18	4231.18	*La-Ni*	4N	2	2-2	6-1
400....	4232.60	4232.64	*V-Nd*	(2) 0	1	5-5	5-5
1000....	4233.40	4233.33	*Fe-Cr*	4	20	...	L4-L2
400....	4233.82	4233.77	*Fe*	6	1	6	3
400....	4234.35	4234.38	*Nd, Ce*	0N	1	3, 2	4, 2
400....	4235.37	4235.39	*Mn-Nd*	(2) 5	3	10-4	20-4
400....	4235.98	4235.94	*V-Y*	(2) 1	1	4-10	5-L6
650....	4236.24	4236.11	*Fe-Y*	8	6	10-10	4-5
		4236.28	*Zr*	1		4	2
350....	4236.72	4236.71	*Zr*	00	0	3	...
450....	4237.24	4237.25	*Fe-Sa-*	(5) 6	2d	1-10	-5
500....	4238.15	4238.19	*Fe-Sc*	3	2	1-3	1-1
500....	4238.55	4238.56	*La*	1Nt?	2	20	10
500....	4239.02	4238.97	*Fe-Gd*	5	2	3-4	2-4
500....	4240.05	4239.99	*Fe-Ce-Nd*	(3) 7	3	2-5-4	1-5-4
400....	4240.68	4240.64	*Zr-Cr-Fe*	(3) 4	0d	8-2-1	3-2-
400....	4241.26	4241.28	*Zr-Pr*	2	1	4-10	-10
600....	4242.40	4242.45	*Cr-Mn-Er*	3	3N	...	L6-L4-L3
400....	4242.91	4242.90	*Cr-Fe*	2	1	3-	3-
500....	4243.32	4243.36	*Nd*	1d?	2	2	1
400....	4243.82	4243.75	*Fe-Zr-Gd*	(3) 6	1d	-1-2	-1-3
400....	4244.80	....	...	...	1N	...	...
500....	4245.44	4245.45	*Fe-*	(2) 6	2	2-	1-
400....	4246.22	4246.21	*Fe*	2	1	1	1
6000....	4247.07	4247.00	*Sc*	5	30	50	100
400....	4247.57	4247.59	*Fe, Nd*	4	1	3, 10	2, 8
500....	4248.42	4248.38	*Fe*	2	2	1	1
550....	4248.84	4248.88	*Ce*	2N	3N	4	6
400....	4249.68	4249.65	–	1N	1	...	...
700....	4250.32	4250.29	*Fe*	8	4	10	4
700....	4251.01	4250.96	*Fe*	(2) 9	5	15	6

TABLE I—*Continued*

Height of Chromosphere	Wave-Lengths		Substance	Intensities			
	Chromosphere	Rowland		Rowland	Chromosphere	Arc	Spark
km							
500....	4251.85	4251.84	*Mn-Gd*	(2) 0	2	–10	L5-10
500....	4252.62	4252.70	*Cr-Nd*	(2) 1	3	–4	L3-7
350....	4253.12	4253.15	–	(3) 3	0	...	...
400....	4253.55	4253.52	*Ce, Gd*	00	1	3, 5	2, 4
600....	4254.52	4254.50	*Cr*	8	15	50	50
350....	4255.46	4255.42	*Fe-Cr-V-Zr*	(4) 5	0	1-1-1-1	1-1-1-1
500....	4256.05	4255.99	*Ce-Fe*	2N	1	3–	2–
500....	4256.60	4256.58	*Zr-Sa*	00	1	3-10	2-5
400....	4257.49	4257.52	*V*	00	0	3	3
400....	4257.81	4257.82	*Mn*	2	1	3	4
400....	4258.37	4258.34	*Zr-Fe*	(3) 3	4N	3–	L8–
400....	4258.74	4258.77	*Fe, Ti*	2	1	1, 1	–, 1
400....	4259.23	4259.26	*Mn-Fe-V*	(4) 4	1N	-1-3	L4-3-
500....	4260.27	4260.23	*Fe*	(2) 5	2d	1	...
600....	4260.67	4260.64	*Fe*	10	8	20	10
500....	4261.58	4261.52	*Cr-Mn*	(3) 4	1	2-1	1-1
500....	4261.98	4262.00	*Cr-Nd*	(3) 4	2	–3	5-4
400....	4263.35	4263.32	*Ti-Cr*	(2) 3	1	8-3	4-3
400....	4264.48	4264.52	*Fe–*	(4) 7	1d	1–	...
400....	4265.36	4265.42	*Fe, V*	2	0	1-3	–3
400....	4266.10	4266.08	*Mn*	2	1	3	5
500....	4266.98	4267.03	*Fe-Nd*	(3) 4	1N	1-4	1-2
350....	4267.55	4267.54	–	2	0	...	...
500....	4267.92	4267.95	*Fe–*	(2) 4	3	2–	1–
400....	4268.20	4268.20	*Zr–*	(2) 1	1	4	2
500....	4268.77	4268.78	*V*	0	2	8	10
400....	4269.68	4269.62	*La*	0	1	6	10
400....	4269.83	4269.90	*V*	2	1	3	3
400....	4270.35	4270.33	*Ti-Ce*	1N	1	3-3	2-3
800....	4271.32	4271.32	*Fe*	6	4	15	4
800....	4271.93	4271.93	*Fe*	15	10	30	10
350....	4272.93	4272.88	*Nd-V*	(2) 2	1	4-1	2-1
600....	4273.52	4273.55	*Zr-Fe*	(2) 5	3	3–	4–
400....	4274.15	4274.21	–	(3) 4	0	...	...
800....	4274.93	4274.96	*Cr*	7d?	20	50	30
500....	4275.70	4275.76	*La-Ce*	(2) 1	2	3-2	4-1
450....	4276.80	4276.84	*Zr-Er*	2	1	3-1	1-3
400....	4277.15	4277.15	*V*	1N	1	5	8
400....	4277.60	4277.65	*Zr–*	(2) 2	1	2–	2–
400....	4278.36	4278.39	*Ti-Fe*	3	2	3-1	2-1
400....	4278.92	4278.96	*Ti-Mn-Ce*	(2) 2	0N	2-1-2	1-1-2
450....	4279.81	4279.76	*Sa–*	(2) 4	2	8	4
450....	4280.14	4280.20	*La, Ti–*	(3) 3	1	4, 1–	1, 1–
450....	4280.57	4280.56	*Cr*	1	1	3	3
450....	4280.88	4280.86	*Sa, Gd*	(2) 2	1	8–	4-3
450....	4281.23	4281.26	*Mn*	2	2	3	5
500....	4282.10	4282.13	–	2N	2	...	...
700....	4282.60	4282.56	*Fe*	5	5	10	3
700....	4283.11	4283.17	*Ca*	4	3	50	20

TABLE I—*Continued*

Height of Chromosphere	Wave-Lengths		Substance	Intensities			
	Chromosphere	Rowland		Rowland	Chromosphere	Arc	Spark
km							
500....	4284.30	4284.34	*Cr-V-Mn*	(2) 3	2N	-8-2	L3-10-2
400....	4284.96	4285.01	*Ti-Ni-Zr*	(3) 4	1	3-1-1	3-1-1
400....	4285.59	4285.61	*Fe-Ce*	(3) 5	2	1-2	1-3
400....	4286.04	4286.07	*Ti–*	(2) 3	2	10–	4–
500....	4286.58	4286.63	*V*	3N	1	2	3
400....	4287.05	4287.11	*La–*	(2) 3	1	6	20
600....	4288.11	4288.13	*Ti-V*	(3) 4	4N	3-2	3-3
500....	4288.85	4288.89	*Ce*	00N	1	3	2
500....	4289.25	4289.24	*Ti*	2	2	15	4
1300....	4289.78	4289.52	*Ca*	4	15	50	20
		4289.88	*Cr*	5		30	30
1300....	4290.33	4290.38	*Ti*	2	15	2	L10
500....	4291.30	4291.30	*Ti-Fe*	(5) 9	3d	13–	4–
500....	4292.25	4292.29	*V-Mn*	(4) 6	3d	8–	8-L2
500....	4293.19	4293.24	*Zr–*	(2) 5	3d	...	L4
1200....	4294.23	4294.27	*Ti, Fe*	(2) 7	15	2, 15	L10, 4
500....	4294.96	4294.94	*Zr-Sc*	2	2	4-5	4-5
500....	4295.25	4295.29	*Dy–*	(2) 6	2	8–	5–
500....	4296.07	4296.06	*Ti-V-La-Gd*	(3) 4	3d	10-5-8-5	4-8-8-4
600....	4296.83	4296.80	*Fe, Zr-Ce*	(3) 4	5	-2-8	L2, L5-8
400....	4297.23	4297.29	*Cr-Gd*	(4) 7	1	2-3	1-4
400....	4297.90	4297.91	*Cr-V-Pr*	0	1	3-3-8	3-4-5
400....	4298.33	4298.36	–	1	1	...	...
500....	4298.88	4298.90	*Ti–*	(2) 4	2	12–	4–
550....	4299.18	4299.15	*Ca*	3	3	30	20
550....	4299.43	4299.41	*Ti, Fe*	4	3	4, 15	3, 4
1200....	4300.31	4300.31	*Ti-Mn-Ce*	(3) 5	15	3-4–	L8-L2-4
500....	4301.24	4301.26	*Ti*	4	2	15	3
750....	4302.10	4302.08	*Ti-Zr*	2	5	2-2	L5-5
750....	4302.75	4302.69	*Ca*	4	2	100	50
750....	4303.41	4303.42	*Fe–*	(2) 3	3d	...	L4–
400....	4303.93	4303.91	*Nd-Er*	(2) 3	1	20-3	10-2
450....	4304.65	4304.67	*Nd-Fe*	(2) 3	1	4-1	5–
600....	4305.62	4305.61	*Sr*	3	3	20	L100
600....	4305.98	4306.01	*Ti-Sc-Pr*	(3) 7	4d	20-8-20	8-6-10
350....	4306.43	(4306.45)	*V-Gd*	...	0	4-4	3-2
500....	4306.89	4306.86	*Ce-Nd*	2	2	4-2	4-2
500....	4307.55	4307.59	–	(2) 4N	1	...	...
750....	4308.01G	4307.91	*Ca*	3	15	30	20
		4308.08	*Fe-Ti*	6		30-4	15-L8
500....	4309.05	4309.00	*Zr-Fe*	(3) 5	0	2-1	4-1
600....	4309.78	4309.79	*Y*	1	4	20	L20
450....	4310.55	4310.54	*Ti*	2	0	1	1
450....	4310.92	4310.86	*Ce*	2	0	1	1
500....	4311.72	4311.72	*Ti-Ce-*	(3) 6	1	1-1-	1-1-
450....	4312.24	4312.25	–	2	0	...	...
600....	4312.98	4313.03	*Ti*	3	10	2	L8
800....	4314.24	4314.25	*Sc*	3	10	30	30
800....	4315.13	4315.14	*Ti*	3	12	1	L8
400....	4316.12	4316.11	*Gd-La*	00	0	5-2	3-1

TABLE I—*Continued*

Height of Chromosphere	Wave-Lengths: Chromosphere	Wave-Lengths: Rowland	Substance	Intensities: Rowland	Intensities: Chromosphere	Intensities: Arc	Intensities: Spark
km							
500....	4316.80	....	...	...	2	...	...
500....	4317.36	4317.35	*Zr*–	(2) 1	1	3–	6–
600....	4318.91	4318.82	*Ca, Ti-V*	4	4	50, 10-4	30, 3-1
800....	4320.93	4320.91	*Sc*	3	15	20	20
500....	4321.76	4321.81	*Ti*	0	1	8	3
500....	4322.58	4322.60	*La-V*	(2) 1	1	6-1	5-2
400....	4323.36	4323.32	–	(4) 4	2d	...	...
400....	4323.89	4323.92	–	(2) 4	0d	...	...
750....	4325.18	4325.15	*Sc*	4	6	20	20
900....	4325.95	4325.94	*Fe-Nd*	8	12	30-15	15-5
450....	4327.20	4327.27	*Fe, Gd*	3	1	1, 10	1, 4
500....	4327.97	4327.96	–	00	1	...	...
500....	4329.10	4329.10	–	(3) 1	1N	...	...
600....	4330.23	4330.19	*V*	0N	2	10	8
600....	4330.82	4330.87	*Ti*	2	3	...	L3
500....	4331.82	4331.81	*Ni*	2	1	3	2
500....	4332.96	4332.99	*V*	0	1	10	8
500....	4333.88	4333.92	*La*	1N	5	20	15
500....	4335.43	4335.43	–	1Nd?	0	...	...
500....	4336.12	4336.08	–	00	1	...	...
600....	4337.28	4337.22	*Fe*	5	2	6	2
900....	4338.04	4338.08	*Ti*	4	15	2	L10
450....	4338.83	4338.85	*Nd-Pr*	0	1	6-4	5-4
8000....	4341.17	4340.63	*Hγ*	20N	80	...	...
350....	4342.29	4342.35	*Gd*	0	1N	10	10
500....	4343.25	....	...	...	2N	...	...
400....	4343.79	4343.86	*Fe*	2	1	...	...
600....	4344.55	4344.60	*Ti, Cr*	(2) 6	5	1-10	L3-10
400....	4346.95	4346.99	*Cr*	1	0	3	2
400....	4347.55	4347.55	*Gd*–	(2) 2	0d	3	3
500....	4348.06	4348.05	*Zr-Sa-Fe*	(2) 3	2	3-10-1	3-6-
400....	4349.10	4349.11	*Fe-Zr*	2	1	1-2	–1
400....	4349.90	4349.97	*Ti-Ce*	00	1	–4	L2-6
400....	4351.30	4351.27	*Cr-Nd*	(2) 3	2	8-10	4-8
600....	4352.02	4352.01	*Cr, Mg*	(2) 10	12	15, 10	10, 2
500....	4352.97	4352.91	*Fe*	4	5d?	4	2
		4353.04	*V*	0		10	6
350....	4353.80	4353.77	*Ce-La*	(4) 1	0	...	...
400....	4354.34	4354.33	*Ti-Nd*	(2) 1	0N	2-1	2–
500....	4354.90	4354.90	*Sc-V*	(2) 2	3	3-2	5-3
350....	4355.24	4355.26	*Eu*	2	0	4	3
350....	4356.17	4356.16	*V-Nd*	1	2	3-3	3-3
350....	4356.88	4356.86	–	(4) 2	1	...	...
500....	4358.29	4358.27	*Nd*–	(4) 2	2N	10–	8–
500....	4358.90	4358.88	*Y-Zr*	0	4	8-3	L10-2
500....	4359.81	4359.82	*Cr, Zr*	(2) 4	5	10, 6	6, L15
350....	4360.53	4360.54	*Ti*–	(2) 2	0	2–	2–
400....	4361.03	4360.96	*Zr*	1	0	5	2
350....	4362.15	....	...	...	0N	...	...
400....	4362.72	4362.69	–	1	1	...	...
450....	4363.34	4363.27	*Cr*	1N	2	3	2

TABLE I—*Continued*

Height of Chromo-sphere	Wave-Lengths		Substance	Intensities			
	Chromo-sphere	Rowland		Rowland	Chromo-sphere	Arc	Spark
km							
450....	4364.35	4364.35	*V-Nd*	1	2	2-3	3-3
450....	4364.82	4364.83	*Ce-La*	00	2	8-3	5-3
350....	4365.49	4365.53	–	([2]) 1	0	...	...
350....	4365.99	4366.06	*Fe*	2	0	1	...
400....	4366.72	4366.75	*Zr–*	([2]) 2	2d	5–	3–
500....	4367.89	4367.84	*Ti*	2	4	1	L6
350....	4368.11	4368.11	*Fe, V*	([2]) 3	0	1, 4	–, 3
400....	4368.65	4368.63	*V-Nd-Pr*	([2]) 1	0	2-4-10	3-4-10
400....	4369.55	4369.57	*Er*	1	1	2	2
500....	4369.88	4369.93	*Fe-Ti-Gd*	([2]) 5	4	3-3-5	2-2-4
500....	4371.17	4371.14	*Zr*	1	3	4	L15
400....	4371.44	4371.44	*Cr*	2	1	10	8
350....	4371.74	4371.77	–	([2]) 1	0N	...	...
400....	4372.41	4372.50	*Ti*	0d?	0	2	2
400....	4373.73	4373.73	*Fe*	2	1N	1	...
550....	4374.65	4374.63	*Sc*	3	10	20	30
550....	4375.16	4375.10	*V-Nd*	2	15	50-10	100-6
500....	4376.16	4376.11	*Fe-Ce*	6	6	5-8	2-3
450....	{4376.97	{4376.94	*Cr*	1	1N	2	2
400....	{4377.40	{4377.38	–	2N	1	...	...
350....	4377.97	4377.95	*Fe*	1	0	...	...
400....	4378.42	4378.42	*Cu-Sa-Er*	2Nd?	2	20-4-2	20-4-2
450....	4379.41	4379.40	*V*	4	3	30	30
400....	4379.92	4379.93	*Zr*	0	2	1	L4
400....	4380.87	4380.88	*Gd*	2Nd	1	2	3
350....	4381.35	4381.33	*Cr*	([2]) 1	0	...	...
400....	4381.80	....	...	...	0	...	...
450....	4382.32	4382.32	*Ce-Er*	00	2	10-3	5-2
400....	4383.15	4383.16	–	0	0	...	...
1600....	4383.70	4383.72	*Fe*	15	15	100	20
400....	{4384.43	{4384.48	*Ni-Pr*	([3]) 2	1	3-3	2-3
450....	{4384.85	{4384.87	*V*	3	2	30	30
400....	{4385.30	{4385.24	*Cr-La*	([3]) 4	0	8-2	5-3
600....	{4385.60	{4385.55	*Fe*	2	5	...	L3
450....	4386.97	4387.01	*Ti-Ce*	1	3	–10	L5-2
400....	4387.65	4387.66	*Cr*	0	0	3	2
2000....	4388.04	(4388.10)	*He*	...	2	...	...
400....	4388.55	4388.57	*Fe-Er*	3	2	2-1	1-3
400....	4389.40	4389.41	*Fe*	2	0	1	...
400....	4390.11	4390.15	*V*	2	2	20	20
350....	4390.63	4390.65	*Fe–*	([2]) 2	1	...	...
500....	4391.12	4391.15	*Ti-Fe-Gd-Sa*	([2]) 3	3d	-1-3-10	L2-1-3-10
500....	4391.83	4391.89	*Cr-Ce*	([2]) 2	3	3-8	2-8
350....	4392.63	....	...	...	0	...	...
400....	4393.17	4393.20	*V*	0	0	2	2
500....	4394.17	4394.19	*Ti*	([2]) 3	3	5	4
2500....	4395.29	4395.29	*Ti-V-Zr*	([2]) 5	25	10-15-3	L20-10-2
500....	4396.05	4396.01	*Ti*	1	2	...	L2
350....	4396.73	4396.79	–	00	0	...	...
400....	4397.34	4397.31	–	00	0N	...	...

TABLE I—*Continued*

Height of Chromosphere	Wave-Lengths: Chromosphere	Wave-Lengths: Rowland	Substance	Intensities: Rowland	Intensities: Chromosphere	Intensities: Arc	Intensities: Spark
km							
750....	4398.32	{4398.18	*Y*	1}	8	10	15
		4398.46	–	0}	...	...	...
800....	4399.95	4399.98	*Ti*	3	12	3	L7
800....	4400.68	4400.60	*Sc, V*	(2) 4	12	20, 10	20, 10
350....	4401.08	4401.02	*Nd-Ni*	0N	0	10-1	5-1
400....	4401.73	4401.71	*Ni*	2	6	15	8
350....	4402.95	....	...	...	0	...	...
400....	4403.52	4403.53	*Zr-Cr*	0	3d	-3	L1-3
400....	4404.43	4404.43	*Ti*	1N	2	10	4
800....	4404.95	4404.93	*Fe*	10	15	50	15
350....	4405.92	4405.90	*Pr*	0Nd?	0	8	5
350....	4406.27	4406.32	*V*	0	0	3	3
400....	4406.84	4406.81	*V-Gd*	2	2	10-5	5-10
350....	4407.20	4407.16	*Nd-Eu*	00	0	3-1	2-5
450....	4407.83	4407.81	*V*	2	2	1	4
450....	4408.48	4408.54	*V*	(2) 4	4d	23	16
400....	4408.82	4408.82	–	00	1	...	...
400....	4409.54	4409.56	*Ti-Er*	(3) 1	2	-5	2-2
300....	4410.29	4410.33	–	00N	0	...	...
500....	4410.69	4410.68	*Ni*	2	2	5	1
500....	4411.24	4411.24	*Ti-Cr-Nd*	1	4	-2-8	L5-2-5
400....	4412.00	4412.07	*Ti-Mn*	(2) 2	0	-3	1-2
500....	4412.31	4412.35	*V-*	(2) 1	2	4-	3-
350....	4413.73	4413.76	–	1	1	...	...
350....	4414.28	4414.28	*Zr, Gd*	00	0	2, 4	3, 1
350....	4414.79	4414.71	*Zr*	00	2	3	4
500....	4415.26	4415.29	*Fe*	8	10	20	20
500....	4415.69	4415.72	*Sc*	3	10	20	20
500....	4417.00	4416.98	*Ce-*	2	8	3-	3-
450....	4417.38	4417.45	*Ti*	0	1	5	2
500....	4417.87	4417.88	*Ti*	3	15	2	L6
500....	4418.36	....	...	...	2	...	...
350....	4419.03	4419.02	*Ce, Gd*	(2) 1	1	8, 5	5, 8
300....	4419.82	4419.77	*Er-Pr*	000	0	10-4	10-3
300....	4420.13	4420.10	*V*	00N	1	3	3
400....	4420.68	4420.69	*Zr-Sa*	00	2	4-10	2-6
350....	4421.41	4421.39	*Gd-Sa-Pr*	(2) 0	0	3-10-4	8-5-3
450....	4422.07	4422.04	*Ti*	(2) 1	2	2	L3
500....	4422.77	4422.74	*Y*	3	3	10	L10
350....	4423.37	4423.34	*V-Fe*	(2) 2	1	3-	3-
350....	4423.98	4424.01	*Fe?*	2	1	...	...
400....	4424.51	4424.46	*Sa, Cr*	0	3	20, 3	10, 2
600....	4425.48	4425.61	*Ca*	4	5	100	20
400....	4426.05	....	...	...	1	...	...
400....	4426.29	4426.20	*Ti-V*	0Nd?	1	4-4	2-4
400....	4426.82	4426.84	*Er*	000Nd?	0N	3	1
600....	4427.43	4427.42	*Ti, Fe*	(2) 7	10	10, 8	4, 2
350....	4427.91	4427.91	*La-Ce*	(3) 0	1	3-4	8-3
350....	4428.55	4428.62	*V-Ce*	(2) 1	1	5-4	4-3
350....	4429.33	4429.37	*Ce-Pr*	00	2	8-30	5-15
450....	4430.15	4430.15	*La*	(2) 0N	4	20	10

TABLE I—*Continued*

Height of Chromosphere	Wave-Lengths: Chromosphere	Wave-Lengths: Rowland	Substance	Intensities: Rowland	Intensities: Chromosphere	Intensities: Arc	Intensities: Spark
km							
450....	4430.70	4430.79	*Fe-Gd*	3	2	5-5	1-2
350....	4431.45	4431.44	*Ti-Sc*	$(^{3})$ 1	1	2-2	1-3
350....	4431.81	4431.78	–	00	0	...	...
350....	4432.37	4432.33	*Cr*	0	0	2	2
300....	4432.86	4432.90	–	00	0	...	...
350....	4433.36	4433.39	*Fe*	3	2	4	1
350....	4434.04	4434.02	*Ti-Fe-Sa*	$(^{3})$ 2	2d	4-1-10	3–6
300....	4434.48	4434.50	*Sa*	00	1	20	8
600....	4435.14	4435.13	*Ca*	5	7	100	20
600....	4435.68	(4435.74)	*Eu*	...	6	50	30
		4435.85	*Ca*	4		50	15
350....	4436.35	4436.31	*V-Gd*	0	2	5-4	5-16
350....	4437.09	4437.11	*Ni*	2d?	2	3	1
750....	4437.86	(4437.72)	*He*	...	...	...	...
		4437.86	*V*	$(^{2})$ 1	1d	10	6
350....	4438.39	4438.39	*Sr, Zr, Ti*	$(^{3})$ 2	1	20, 3, 2	4, 2, 1
300....	4438.73	4438.74	–	$(^{2})$ 0	0	...	...
300....	4439.47	4439.52	–	00	0	...	...
300....	4440.00	4440.05	*Fe*	1	0	...	...
350....	4440.53	4440.59	*Zr-Ti*	1	3	3-4	L5-2
300....	4441.08	4441.04	*Ce-Fe*	$(^{2})$ 2	1d	3–	2–
350....	4441.90	4441.88	*V*	3Nd?	3	10	8
350....	4442.49	4442.51	*Fe*	6	3	8	2
400....	4443.19	4443.16	*Zr*	0	3	5	L15
1600....	4444.01	4443.98	*Ti*	5	20	4	L15
450....	4444.76	4444.73	*Ce-Ti*	2	4	13–	7-1
300....	{4445.39	....	...	...	0	...	...
300....	{4445.83	4445.84	–	00	0	...	...
350....	4446.39	4446.41	*Nd*	00	3	10	10
350....	4447.17	4447.16	*Fe, Mn*	$(^{2})$ 4	2d	2-1	–4
450....	4447.89	4447.89	*Fe*	6	4	8	2
400....	4449.34	4449.31	*Ti*	2	4	10	5
350....	4449.85	4449.88	*V-Pr-Dy*	00	2	2-10-10	3-4-4
600....	4450.53	4450.59	*Ti-Zr*	$(^{2})$ 3	8	1-3	L4-2
350....	4450.93	4450.92	*Ce*	00	2	8	4
500....	4451.71	4451.75	*Fe-Mn-Nd*	3	3	2-5-10	L3-10-10
300....	4452.17	4452.17	*V*	0N	1	10	10
400....	4452.92	4452.90	*Sa–*	$(^{3})$ 1	1d	10–	5–
350....	4453.46	4453.49	*Ti*	2	1	8	3
350....	4453.88	4453.88	*Ti*	1	1	8	3
500....	4454.57	4454.55	*Zr-Fe*	3	2	–2	L2-1
500....	4454.93	4454.95	*Ca-Zr*	5	6	200-4	30-5
400....	4455.45	4455.48	*Ti-Mn*	2	2	12-3	4-3
500....	4456.02	4456.03	*Mn, Ca*	$(^{2})$ 5	3d	3, 20	3, 15
350....	4456.68	4456.70	*V, Nd, Ca*	$(^{2})$ 3	1N	2, 3, 8	3, 4, 5
300....	4457.20	4457.21	*Mn*	0	0	4	2
500....	4457.68	4457.66	*Ti-Zr-V-Mn*	$(^{2})$ 4	3d	15-3-4-4	5-5-3-4
300	4458.24	4458.24	–	2	0	...	...
350....	4458.76	4458.69	*Cr-Sa*	0	0	3-8	3-6

TABLE I—*Continued*

Height of Chromosphere	Wave-Lengths		Substance	Intensities			
	Chromosphere	Rowland		Rowland	Chromosphere	Arc	Spark
km							
450....	4459.27	4459.26	*Ni, Fe*	(^{2}) 5	3	10, 10	8, 3
300....	4459.52	4459.52	*Cr*	1	0	1	...
350....	4459.97	4459.92	*V*	1	1	8	6
350....	4460.53	4460.49	*V, Ce*	(^{2}) 1	4	10, 10	10, 10
350....	4461.28	4461.30	*Mn, Zr, Ce*	(^{2}) 2	2	5-5	4-L1-14
500....	4461.75	4461.82	*Fe*	4	4	10	2
350....	4462.14	4462.16	*Fe, Mn*	3Nd?	2	-10	L2-8
350....	4462.68	4462.62	*V-Ni*	1	1	8-8	10-3
350....	4463.18	4463.15	*Nd*	00	2	10	15
350....	4463.67	4463.63	*Ti-Ni-Ce*	(^{2}) 1	2	8-1-5	2-4
500....	4464.72	4464.73	*Ti-Mn*	(^{2}) 4	6d	1-8	L3-5
300....	4465.46	4465.52	*Cr*	0	0	2	2
350....	4465.88	4465.91	*Ti-Nd*	(^{2}) 1	1	5-3	3-3
500....	4466.75	4466.73	*Fe*	5	4	10	3
300....	4467.09	4467.10	*Co-Zr*	1	0	5-3	3-2
350....	4467.46	4467.50	*Sa*	00	1	10	10
300....	4467.94	4467.96	*V-Nd-Ce*	(^{3}) 1	0	3-3-4	3-3-3
1500....	4468.71	4468.66	*Ti*	5	20	4	L15
400....	4469.53	4469.54	*Fe*	4	2	6	3
350....	4469.76	4469.78	*Co, V*	(^{2}) 1	0	5-5	8-8
350....	4470.27	4470.30	*Mn*	1	0	3	4
400....	4470.63	4470.65	*Ni-Zr*	2	2	10-4	3-3
7500....	4471.71	4471.65	*He*	...	40	...	...
300....	4472.55	4472.58	*Sa*	00	0	4	3
400....	4473.04	4472.97	*Mn-Ce-Fe*	(^{3}) 2	4	8-4-	3-3-
300....	4474.21	4474.21	*V*	00	0	4	5
300....	4474.90	4474.91	*V*	00	1	5	5
300....	4475.71	4475.74	*Ti-Nd*	00	0	1-1	1-
500....	4476.20	4476.18	*Fe*	4	5	10	4
300....	4476.97	....	...	...	0	...	...
300....	4477.42	4477.43	*Y-Pr*	(^{2}) 0	0d	4-6	2-3
300....	4478.13	4478.19	–	0	1	...	...
300....	4478.89	4478.89	*Mn-Gd-Sa*	(^{2}) 0	0	-4-5	L2-5-5
350....	4479.72	4479.74	*Ce-Ti-Mn*	(^{3}) 2	2d	10-4-1	4-2-1
350....	4480.24	4480.25	*V*	(^{2}) 1	1	3	3
300....	4480.70	4480.75	*Ti-Ni*	0N	0	3-1	1-
400....	4481.39	4481.40	*Mg, Ti*	(^{2}) 1	3d?	-, 8	L50, 3
500....	4482.39	4482.38	*Fe*	(^{2}) 8	5	10	4
300....	4482.87	4482.90	*Ti*	1	2	3	2
300....	4483.45	....	...	...	0	...	...
350....	4484.29	4484.34	*Fe-Ce*	(^{2}) 4	2N	4-4	4-2
350....	4485.82	4485.85	*Fe*	3	3	2	1
350....	4487.09	4487.08	*Ce*	0	3	10	4
300....	4487.53	4487.53	*Y*	00	0	7	6
350....	4488.40	4488.40	*Ti*	(^{2}) 2	3	1	L6
300....	4488.76	....	...	...	0	...	...
400....	4489.37	4489.35	*Fe*	2	6	...	L1
400....	4489.89	4489.91	*Fe*	4	1	3	1
400....	4490.26	4490.25	*Mn-Fe*	3N	2	5-1	3-1
350....	4490.82	4490.88	*Fe-Ni*	(^{2}) 2	1	1-1	1-
450....	4491.63	4491.57	*Fe*	2	6	...	L2

TABLE I—*Continued*

Height of Chromo-sphere	Wave-Lengths		Substance	Intensities			
	Chromo-sphere	Rowland		Rowland	Chromo-sphere	Arc	Spark
km							
350....	4492.66	4492.66	*Cr-Fe*	(²) 1	1d	2–	2–
350....	4493.67	4493.70	*Ba*	1	2	6	1
300....	4494.14	4494.18	–	(²) 1	0	...	...
400....	4494.71	4494.74	*Fe-Zr*	6	3	10–	5-L15
350....	4495.53	4495.54	*Ce-Ti*	(⁴) 3	1	3–	2–
350....	4496.32	4496.32	*Ti-V*	1	2	10-3	3-6
400....	4497.11	4497.14	*Zr*	0	3	3	15
300....	4498.11	4498.03	*Ce, Nd*	000	0	3, 3	3, 3
350....	{4499.02	4499.07	*Mn*	1	0	8	4
350....	{4499.62	4499.67	*Sa*	000	0	4	3
350....	4500.43	4500.45	*Cr*	0	1	3	2
1600....	4501.45	4501.45	*Ti*	5	20	4	L15
300....	4501.97	4501.95	*Nd*	0Nd?	0	8	5
300....	4502.45	4502.39	*Mn*	2	0	8	4
300....	4505.00	4505.00	*Fe*	1	0	1	1
350....	4505.56	4505.52	–	(³) 1	0d	...	...
300....	4506.51	4506.50	*Gd-Ti*	00	0	7-1	4-1
350....	4506.92	4506.90	*Mn–*	(³) 1	1d	1–	...
300....	4507.47	4507.40	*Zr*	0	0	10	3
600....	4508.49	4508.46	*Fe*	4	8	...	L5
300....	4509.46	4509.46	*Ni-V*	0N	1	–1	L2-2
300....	4510.04	4509.99	–	(²) 1	0	...	...
300....	4511.26	4511.23	*Ti*	00	0	2	1
350....	4511.91	....	...	...	1	...	...
450....	4512.90	4512.91	*Ti*	3	2	15	4
300....	4514.09	....	...	...	0	...	..
350....	4514.56	4514.51	*Cr-V-Gd*	(³) 3	2d	8-2-3	3-3-5
600....	4515.48	4515.51	*Fe*	3	6	...	L4
300....	4516.45	4516.44	*Nd*	0N	0	3	3
350....	{4517.72	4517.70	*Fe*	3	1	2	1
400....	{4518.20	4518.20	*Ti*	3	2	15	4
400....	{4518.47	4518.51	–	1	3	...	...
350....	4519.64	....	...	...	1	...	...
600....	4520.38	4520.40	*Fe*	3	8	1	L3
400....	4521.35	4521.30	*Cr*	0	1	2	2
350....	4522.50	4522.54	*La*	00	1	8	15
600....	4522.83	4522.83	*Fe-Ti-Eu*	(³) 6	12	2-15-20	L6-4-L20
350....	4523.23	4523.25	*Ce-Sa*	0	1	5-8	4-4
350....	4524.05	4524.09	*Sa*	00	1	8	5
350....	4524.81	4524.86	–	0	1	...	...
350....	4525.31	4525.31	*Fe-Ba*	5	3	4-10	3-50
350....	4526.26	4526.27	*La*	0	1	5	8
350....	4527.10	4527.10	*Ca-Er*	3	1	20-3	2-3
400....	4527.49	4527.49	*Ti-Ce*	3	3	15-10	4-5
400....	4528.76	4528.80	*Fe-V*	8	5	10-1	6-L6
400....	4529.71	4529.74	*Ti-V-Al*	(³) 3	4d	–3–	L3-2-L8
400....	4531.08	4531.12	*Co*	2	1	15	10
400....	4531.33	4531.33	*Fe*	5	3	5	2
350....	4531.80	4531.80	*Fe*	2	1	...	...
400....	4533.34	4533.32	*Ti–*	(²) 5	2d	20–	5–
1200....	4534.20	4534.17	*Ti-Co*	(²) 7	15	2-3	L5-4

TABLE I—*Continued*

Height of Chromosphere	Wave-Lengths		Substance	Intensities			
	Chromosphere	Rowland		Rowland	Chromosphere	Arc	Spark
km							
400....	4534.89	4534.95	*Ti*	4	2	15	4
400....	4535.74	4535.74	*Ti*	3	3	8	3
400....	4536.15	4536.16	*Ti*	(2) 4	3	20	4
300....	4536.72	4536.68	*Sa*	00	0	4	2
300....	4537.34	4537.39	*Ti*	00	0	1	1
350....	4538.00	4537.94	*V-Gd-Sa*	(2) 1	1N	2-4-8	3-3-4
350....	4539.17	4539.17	*Ti-Fe-Ce*	(5) 2	0N	2-1	1-1
400....	4539.96	4539.95	*Ce-Cr*	0N	3	10-3	4-3
400....	4540.77	4540.78	*Cr*	(2) 4	2	6	7
400....	4541.66	4541.64	*Fe-Cr-Nd*	(2) 3	4d	1-1-5	L3-1-5
300....	4542.23	4542.23	*Sa-Gd*	000	0	8-2	3-1
350....	4542.42	4542.40	*Zr*	0N	1	6	3
350....	4542.87	4542.83	*Nd–*	(2) 1	1	4–	5–
350....	4543.40	4543.40	–	0	0	...	...
400....	4544.11	4544.12	*Co-Ti-Sa*	(2) 2	2d	3–10	4-1-5
400....	4544.84	4544.84	*Ti-Cr*	(2) 4	2	15-4	3-4
400....	4545.28	4545.31	*Ti*	1	2	...	1
400....	4546.12	4546.13	*Cr*	3	2	5	4
350....	4546.85	4546.85	–	00	0	...	...
400....	4547.20	4547.15	*Ni-Fe*	(3) 4	2	6-1	3-1
400....	4548.02	4548.02	*Fe*	3	2	3	2
400....	4549.00	4548.94	*Ti*	2	0	8	3
1300....	4549.80	4549.77	*Ti-Fe-Co*	(2) 8	20	3-1-4	L20-L7-5
350....	4550.80	....	...	...	1	...	...
350....	4551.33	4551.40	*Ni*	0	1	1	1
400....	4552.63	4552.63	*Ti*	2	3N	15	4
300....	4553.16	4553.21	*Zr, V*	00	0	4-3	1-5
1200....	4554.28	4554.21	*Ba-Zr*	8	20	1000–	L1000-8
350....	4555.02	4554.98	*Cr-Sa*	(2) 3	1	1-5	L6-3
350....	4555.69	4555.66	*Ti-Zr*	3	2	15-3	3-2
500....	4556.06	4556.06	*Fe-Cu*	3	10	...	L5-L5
300....	4557.46	4557.46	–	0N	0	...	...
500....	4558.74	4558.79	*Cr-La*	(2) 3	8d	1-5	L20-5
300....	4559.54	4559.52	*La, Y*	000	0	3, 4	3, 2
350....	4560.26	4560.27	*Fe*	2	1	1	1
450....	4560.50	4560.52	*Ce-Sa*	(2) 0	2	5-5	5-3
350....	4560.87	4560.89	*V*	00	0	8	9
400....	4561.18	4561.14	*Ce*	00	1	4	3
300....	4561.59	4561.59	–	1	0	...	...
450....	4562.47	4562.54	*Ce*	1	4	10	10
350....	4563.18	....	...	...	1	...	...
1200....	4563.93	4563.94	*Ti*	4	15	3	L10
350....	4564.79	4564.75	*V*	00	1	1	L10
400....	4565.67	4565.69	*Cr-Zr*	3	2	4-2	2-2
400....	4565.88	4565.84	*Co*	2	1	8	8
350....	4566.38	4566.41	*Sa*	00N	0	10	5
300....	4566.96	....	...	...	0	...	...
300....	4567.84	....	...	...	0	...	...
300....	4568.36	....	...	...	1	...	...
350....	4568.88	4568.85	*Fe–*	(2) 2	1	1	1
300....	4569.56	4569.61	*Co-Cr*	(2) 0	1	–4	L2-3

TABLE I—*Continued*

Height of Chromosphere	Wave-Lengths		Substance	Intensities			
	Chromosphere	Rowland		Rowland	Chromosphere	Arc	Spark
km							
300....	4570.08	....	...	...	0	...	...
300....	4570.84	....	...	...	0	...	...
400....	4571.25	4571.28	*Mg*	5	3	5	...
1200....	4572.17	4572.16	*Ti*	6	20	5	L20
300....	4574.05	(4574.02)	*Ba*	...	0	10	5
350....	4574.91	4574.90	*Fe*	2	1	1	1
500....	4576.49	4576.51	*Fe*	2	4	...	L1
350....	4577.37	4577.36	*V*	0	1	8	8
350....	4577.82	4577.87	*Sa*	00	1	10	5
350....	{4578.71	4578.73	*Ca*	3	0	20	4
350....	{4578.97	4578.91	*V*	00N	1	4	4
300....	{4579.41	4579.45	*V, Nd*	(2) 0	1	2, 5	2, 4
400....	{4580.12	4580.22	*Cr-La*	3	3	8-3	4-3
400....	{4580.59	4580.59	*V*	1	2	8	10
350....	4581.59	4581.58	*Ca*	4	3	30	4
300....	4582.38	....	...	...	0	...	...
450....	4582.84	4582.83	–	(2) 1	2d	...	...
1100....	4584.04	4584.02	*Fe-V*	4	15	1-2	3-L8
350....	4584.93	4584.97	*Fe-Sa*	(2) 3	1d	1-5	1-4
300....	4585.45	4585.52	–	0	0	...	...
400....	4586.08	4586.05	*Ca*	4	2	30	8
400....	4586.48	4586.48	*V-Cr*	(2) 2	2	10-1	8-1
350....	4587.28	4587.31	*Fe*	2	1	1	1
600....	4588.37	4588.38	*Cr*	3	5	1	L20
500....	4590.10	4590.13	*Ti*	3	6	1	L3
300....	4590.72	(4590.72)	*Zr*	...	0	3	2
350....	4591.39	4591.42	*V*	00	1	4	8
350....	4591.56	4591.57	*Cr*	2	2	8	2
350....	4592.09	4592.16	*Cr-Sa*	(2) 1	2	–3	L4-3
350....	4592.70	4592.71	*Ni*	2	3	10	4
300....	4593.70	4593.70	*Sa*	1	1	4	4
400....	4594.16	4594.20	*V-Eu-Ce*	(3) 3	3d	10-50-10	10-20-10
300....	4594.80	4594.82	*Co-Nd*	00N	0	10-3	3-2
350....	4595.45	4595.53	*Fe-Sa*	2	2	1-5	1-5
350....	4596.04	4596.10	*Cr-Fe*	(2) 3	1N	3–	2–
350....	4597.15	4597.12	*Co-Nd-Gd*	(2) 1	1d	10-3-4	3-3-4
350....	4597.90	4597.93	–	1	2	...	...
300....	4598.31	4598.30	*Fe*	3	1	2	1
300....	4598.92	4598.92	–	0	0	...	...
300....	4599.84	....	...	...	0	...	...
350....	4600.34	4600.31	*V-Cr*	(2) 1	1	1-3	L8-2
400....	4600.91	4600.93	*Cr*	3	2	5	3
350....	4601.33	4601.28	*Cr-Gd*	(2) 1	1	3-5	2-5
350....	4602.20	4602.18	*Fe*	3	2	2	...
400....	4603.12	4603.13	*Fe*	6	3	5	2
300....	4603.78	4603.80	–	00	0	...	...
300....	4604.70	4604.74	–	2	0	...	...
350....	4605.13	4605.17	*Ni*	3	2	10	3
300....	4605.84	4605.77	–	2	1	...	...
350....	4606.46	4606.45	*Ni-Ce*	(2) 2	2d	3-4	2-5
350....	4607.48	4607.51	*Sr*	1	2	1000	50

TABLE I—*Continued*

Height of Chromosphere	Wave-Lengths		Substance	Intensities			
	Chromosphere	Rowland		Rowland	Chromosphere	Arc	Spark
km							
350....	4607.84	4607.83	*Fe*	4	1	2	1
300....	4608.36	....	...	...	0	...	...
300....	4609.43	4609.45	–	0	1	...	...
300....	4610.09	4610.09	–	0	1	...	...
400....	4611.46	4611.47	*Fe-Er*	5	3	4-4	2-2
300....	4611.99	....	...	...	0	...	...
300....	4612.64	....	...	...	0	...	...
400....	4613.50	4613.46	*Cr-La-Fe*	(2) 6	4	8-5-2	3-5-1
350....	4614.10	4614.10	*Zr*	1	2	1	3
300....	4614.58	4614.62	*Ti-Gd*	00	1	1-3	1-2
300....	4615.74	4615.74	*Sa*	1	2	14	14
400....	4616.26	4616.30	*Cr*	4	3	10	4
350....	4616.80	4616.80	*Cr*	1N	1	...	L3
350....	4617.47	4617.45	*Ti*	3	2	10	8
300....	4618.13	4618.15	–	00	0	...	...
600....	4618.98	4618.97	*Cr-Fe*	4d?	4	-1	L8-1
350....	4619.47	4619.47	*Fe*	3	2	3	1
300....	4619.98	4619.96	*V-La*	00	0	8-4	10-6
400....	4620.72	4620.69	*Fe?*	1	4	...	...
300....	4621.36	....	...	...	1	...	...
350....	4622.08	4622.10	*Cr*	(2) 1	2d	3	2
350....	4622.57	4622.63	*Cr*	1	1	2	2
350....	4623.27	4623.28	*Ti*	2	3	10	4
300....	4624.57	4624.59	*V*	00N	0	3	3
350....	4625.20	4625.23	*Fe*	5	2	3	1
400....	4626.39	4626.36	*Cr*	5	3	10	5
300....	4626.78	4626.72	*V, Mn*	0	0	3, 4	2, 2
300....	4627.61	4627.64	*Eu*	(2) 1	1d	50	15
400....	4628.42	4628.34	*Ce*	0	3	10	10
800....	4629.63	4629.52	*Ti-Fe-Co*	6	12	8-10	3-L4-5
300....	4630.32	4630.31	*Fe*	4	1	2	...
300....	4632.36	4632.32	*Cr*	0	0	2	1
400....	4632.99	4633.06	*Fe–*	(2) 5	2	3	1
300....	4633.43	4633.43	*Cr*	0	0	2	1
300....	4633.94	4633.95	–	0N	0	...	...
500....	4634.21	4634.25	*Cr-Zr*	2	3	-10	L10-3
300....	4636.00	4636.03	*Fe*	2	0	1	...
300....	4636.48	4636.50	–	0	0	...	...
300....	4637.31	4637.35	*Cr*	0	0	2	1
350....	4637.66	4637.68	*Fe*	5	1	3	1
350....	4638.19	4638.19	*Fe*	4	2	3	1
350....	4639.69	4639.69	*Ti*	(2) 4	2	8	4
350....	4640.34	4640.29	*Ti-V*	(2) 2	2d	4-3	2-3
300....	4641.31	4641.31	–	(2) 1	0N	...	...
350....	4642.48	4642.42	*Sa*	00	2	10	4
400....	4643.58	4643.64	*Fe*	4	2	2	...
350....	4644.36	4644.39	–	(3) 1	1N	...	...
350....	4645.48	4645.52	*Ti–*	(2) 1	1	5–	3–
600....	4646.33	4646.35	*Cr*	5	5	20	10
300....	4646.89	4646.86	*Cr-Sa*	(2) 1	1	2-5	1-3
500....	4647.63	4647.62	*Fe*	4	2	3	2

TABLE I—*Continued*

Height of Chromosphere	Wave-Lengths		Substance	Intensities			
	Chromosphere	Rowland		Rowland	Chromosphere	Arc	Spark
km							
300....	4648.22	4648.19	*Cr*–	(2) 1	0	2–	1–
500....	4649.03	4648.96	*Ni-Cr*	(4) 5	2d	15-2	3-2
300....	4649.62	4649.61	*Cr*	0	0	3	2
300....	4650.20	4650.19	*Ti*	0	0	3	2
400....	4651.46	4651.46	*Cr*	4	2	8	3
400....	4652.33	4652.34	*Cr*	5	3	10	5
350....	4653.59	4653.61	–	(2) 0	0	...	...
350....	4654.28	4654.33	*Cr*	0	0	1	...
350....	4654.81	4654.80	*Fe*	5	3d	5	2
300....	4655.90	4655.90	*Ti, Ni*	(2) 1	1N	1, 2	1, 1
350....	4656.61	4656.64	*Ti*	3	1	8	3
400....	4657.27	4657.30	*Ti-V*	(2) 3	3d	–1	L2-1
300....	4660.36	4660.40	–	(4) 1	0d?	...	...
300....	4662.14	4662.15	*Fe, Eu*	1	0	1, 50	1, 15
300....	4662.94	4662.99	–	(3) 1	0N	...	...
350....	4663.52	4663.52	*Cr, Co*	(2) 2	1	3, 10	2, 5
350....	4663.99	4663.96	*La, Cr*	1	2	4, 3	8, 2
250....	4664.51	4664.50	–	00N	0	...	...
300....	4665.00	4664.96	*Cr*	3	0	5	2
300....	4666.26	4666.23	*Cr-V*	(2) 2	1d	3-2	3-3
400....	4666.91	4666.89	*Cr*–	(4) 4	3N	1–	2–
400....	4667.79	4667.77	*Ti*	3	3	10	5
350....	4668.30	4668.30	*Fe*–	(2) 6	1d	4	2
350....	4669.62	....	...	...	2d	...	...
500....	4670.55	4670.59	*Sc*	2	4	8	10
300....	4671.57	4671.60	–	1	0	...	...
350....	4672.51	4672.51	–	3N	1	...	...
350....	4673.32	4673.35	*Fe*	4	2	2	1
350....	4674.30	4674.28	–	1N	0	...	...
350....	4674.82	4674.83	*Sa*	0N	1	10	5
300....	4675.89	....	...	...	0	...	...
350....	4677.03	4677.10	*Ti, Sa*	00	0	1, 8	1, 4
250....	4677.59	4677.60	*Ti*	00	0	1	1
350....	4679.19	4679.12	*Fe-Ni-Er*	(2) 8	2N	4–8	2-L3-5
350....	4680.31	4680.32	*Zn*	1	1	100	300
350....	4680.89	4680.90	*Nd*–	(3) 1	1	3–	3–
300....	4681.63	4681.65	–	1	0	...	...
400....	4682.12	4682.09	*Ti*	3	2	10	6
350....	4682.58	4682.53	*V-Co*	1	2	4-10	10-4
300....	4683.70	4683.74	*Fe*	3	1	1	1
300....	4684.42	4684.46	–	(2) 0N	1	...	...
350....	4685.39	4685.39	*Zr-Ca*	2	1d	1-5	5-1
2000....	4686.00	(4685.98)*	*H*	...	1N	...	...
300....	4686.35	4686.40	*Ni*	3	1	6	3
300....	4687.50	4687.51	*Fe*–	(3) 3	0d	...	...
300....	4687.94	4687.98	*Zr*	0	0	15	8
300....	4688.72	4688.70	*Zr-Sa*	(2) 1	1N	10-3	4-1
350....	4689.50	4689.54	*Cr*	2	1	3	3
300....	4690.31	4690.32	*Fe*	4	0	1	1
300....	4690.95	4690.98	*Ti*	00	0	2	1

* Fowler's value, *M.N.*, 73, 62, 1913.

TABLE I—*Continued*

Height of Chromosphere	Wave-Lengths: Chromosphere	Wave-Lengths: Rowland	Substance	Intensities: Rowland	Intensities: Chromosphere	Intensities: Arc	Intensities: Spark
km							
400....	4691.69	4691.62	*Fe-Ti*	(3) 7	3	4-5	2-3
300....	4692.75	4692.70	*C?*	00N	0	...	...
300....	4693.22	....	*C?*	...	0	...	...
300....	4693.97	4694.03	*Ti, Cr*	(2) 2	0	2, 2	2, 2
300....	4694.98	4695.04	*Cr*	1	0	1	...
300....	4695.45	4695.48	*Cr-C*	(2) 1	0	2–	1–
300....	4696.09	4696.03	–	00	0	...	...
300....	4696.74	4696.74	*C?*	(2) 0	0	...	...
300....	4697.40	4697.35	*Cr-C**	(2) 2	1	2–	2–
300....	4698.33	....	...	...	0	...	...
350....	4698.83	4698.80	*Ti-Cr*	(3) 3	3d	10-4	3-4
350....	4699.52	4699.51	*V-Sa*	4	1	2-3	1-2
350....	4700.33	4700.34	–	4	0	...	...
300....	4701.26	4701.23	*Fe*	1	0	1	1
300....	4701.69	4701.71	*Ni*	1	1	8	1
300....	4702.11	4702.08	*C*	0N	0	...	...
500....	4703.16	4703.18	*Mg*	10	3	20	5
350....	4703.93	4703.99	*Ni*	3	1	5	1
300....	4704.53	4704.58	*Sa–*	(3) 1	0N	8–	3–
300....	4705.10	4705.13	*Fe*	4	1	1	...
350....	4706.69	4706.73	*V, Nd*	0	1	2, 8	3, 4
350....	4707.48	4707.52	*Fe–*	(2) 7	2	6	2
300....	4708.18	4708.20	*Cr*	2	1	10	3
350....	4708.80	4708.85	*Ti*	2	2	...	2
300....	4709.10	4709.15	*Ti*	1	1	1	...
350....	4709.89	4709.90	*Mn, Nd*	2	2	8, 5	2, 4
350....	4710.41	4710.45	*Fe-Ti*	(2) 3	3	3-8	1-3
300....	4711.67	4711.66	*C*	0	1	...	...
250....	4712.27	4712.26	*Ni*	0	0	2	1
6000....	4713.32	4713.31	*He*	...	4	...	...
300....	4714.16	4714.21	*V, Ce*	(3) 1	0	3, 3	3, 3
400....	4714.58	4714.60	*Ni*	6	3	15	8
300....	4715.14	4715.09	*C*†	000	1	...	...
350....	4715.98	4715.95	*Ni*	4	2	10	3
300....	4717.00	4717.02	–	00	0	...	...
300....	4717.69	4717.67	*Zr–*	(2) 1	0	3	1
300....	4717.94	4717.89	*V-Sa*	000	0	3-4	3-3
350....	4718.61	4718.60	*Cr*	3	2	10	5
300....	4719.32	(4719.30)	*Zr*	...	0	5	3
300....	4719.70	4719.69	–	0	1	...	...
300....	4721.20	4721.18	*Fe*	2	1d	1	1
400....	4722.34	4722.34	*Zn*	3	3	200	500
300....	4723.48	4723.41	*Ti–*	(2) 0	0d	3–	2–
300....	4724.48	(4724.52)	*Nd*	...	1N	5	5
250....	4726.31	4726.33	*Fe?*	0	0	...	...
350....	4727.62	4727.62	*Fe, Mn*	(2) 5	2d	2, 8	1, 2
250....	4728.33	4728.35	–	0	0	...	...
350....	4728.75	4728.73	*Fe-Y*	4	2	2-5	1-3
300....	4729.64	....	...	...	0	...	...

***Third edge of fourth carbon band.**
† Second edge of fourth carbon edge.

TABLE I—*Continued*

Height of Chromo-sphere	Wave-Lengths		Substance	Intensities			
	Chromo-sphere	Rowland		Rowland	Chromo-sphere	Arc	Spark
km							
300....	4730.22	4730.21	–	2	1	...	...
300....	4731.06	4731.00	*Cr–*	([2]) 2	1	4	3
400....	4731.64	4731.65	*Fe–*	4	3	1–	1–
300....	4731.92	4731.98	*Ni-Nd*	1	0	3-3	1-2
300....	4732.64	4732.64	*Ni-Y*	1	1	3-4	1-3
400....	4733.79	4733.78	*Fe*	4	2	3	1
350....	4734.26	4734.28	*Sc*	1	1	5	3
250....	4736.04	4736.03	*Fe*	3	1	1	1
400....	4736.97	4736.96	*Fe*	6	3	6	3
350....	4737.51	4737.54	*Cr*	2	2N	6	3
250....	4737.82	4737.82	*Sc*	1	1	5	3
350....	4739.30	4739.29	*Mn*	3	2	5	2
300....	4739.80	....	...	...	0	...	...
350....	4740.46	(4740.46)	*La*	...	2d	8	5
350....	4741.48	(4741.41)	*Sc-Y*	...	0N	5-4	3-3
300....	4741.74	4741.72	*Fe*	3	1	2	1
300....	4742.10	(4742.10)	*Sr*	...	0	10	3
300....	4743.23	(4743.26)	*La*	...	1	8	10
300....	4744.56	4744.57	–	3	1	...	...
300....	4745.52	4745.50	*Cr*	00	0	2	1
350....	4745.93	4745.99	*Fe*	4	2	2	1
250....	4748.36	4748.32	–	4	1	...	...
300....	4749.95	4749.99	*Co-Fe*	([2]) 2	2d	10	4
250....	4751.29	4751.28	*V*	0	1	3	3
250....	4752.20	4752.29	*Cr-Ni*	2	1	3-2	3-1
300....	4752.60	4752.61	*Ni*	3	2	3	1
400....	4754.17	4754.22	*Mn*	7	3	30	8
300....	4754.92	4754.95	*Ni*	1	1	3	1
300....	4755.82	4755.89	–	00	0	...	...
300....	4756.25	4756.30	*Cr*	2	1	8	8
300....	4756.67	4756.70	*Ni*	3	2	8	3
300....	4757.73	4757.77	*V-Fe*	2	1	5-1	4-1
300....	4758.29	4758.31	*Ti*	1	2	10	5
350....	4759.50	4759.46	*Ti*	2	2	8	5
250....	4760.26	4760.26	–	00	0	...	...
250....	4761.28	4761.29	*V*	00N	1	5	3
350....	4761.74	4761.72	*Mn*	3	2	6	2
400....	4762.67	4762.61	*Mn-Er*	([2]) 6	3d	10-5	4-3
300....	4763.02	4762.97	*Zr-Ti*	0	0	5–	2-1
350....	4764.17	4764.11	*Ti-Ni*	4d	4	–3	L1-2
300....	4764.72	4764.72	*Ti*	0	1	...	1
300....	4765.64	4765.65	–	2	1N	...	...
300....	4766.07	4766.05	*Mn*	3	1	6	3
350....	4766.55	4766.62	*Mn*	4	2	8	3
250....	4768.05	4768.05	*Cr*	00	0	...	...
300....	4768.45	4768.52	–	3	2	...	...
250....	4769.97	4769.99	*Ti*	00N	0	1	1
300....	4771.32	4771.28	*Ti, Co*	00	0	1, 5	1, 3
350....	4771.79	4771.76	*Fe–*	([2]) 5	1d	1–	...
350....	4772.97	4773.01	*Fe*	4	1	2	1
250....	4773.55	4773.60	–	00	0	...	...

TABLE I—*Continued*

Height of Chromo-sphere	Wave-Lengths		Substance	Intensities			
	Chromo-sphere	Rowland		Rowland	Chromo-sphere	Arc	Spark
km							
250....	4776.30	4776.26	*Fe*	00	0	...	...
300....	4776.59	4776.55	*V-Co*	0d?	1	10-4	10-3
300....	4777.83	....	...	...	0N	...	...
250....	4779.59	4779.63	*Fe*	1	0	1	...
500....	4780.15	4780.17	*Ti-Co*	2	4	−4	L4-5
250....	4781.66	4781.64	*Co*	000	0	3	2
500....	4783.65	4783.61	*Mn*	6	4	30	8
250....	4786.18	4786.14	*Nd-Sa*	0	0	3-3	2-1
450....	4786.78	4786.73	*Ni-V-Y*	3	3N	15-5-3	3-10-L5
300....	4787.84	....	...	...	0N	...	...
300....	4788.92	4788.95	*Fe*	3	0	2	1
400....	4789.65	4789.72	*Cr, Fe*	(2) 5	3d	5, 3	3, 2
300....	4791.33	4791.33	–	0	1d	...	...
350....	4792.57	4792.65	*Ti-Cr-*	(2) 2	2	4-4-	3-3-
350....	4793.10	4793.04	*Co*	1	2	10	8
250....	4794.01	....	...	...	0	...	...
250....	4794.56	4794.55	–	00	0	...	...
250....	4798.47	4798.45	*Fe*	1	0	1	1
400....	4798.80	4798.79	–	(2) 1	2d	...	...
300....	4799.64	4799.60	*Nd*	1	1	3	2
300....	4799.98	4799.98	*Ti*	1	1	3	3
300....	4800.82	4800.84	*Fe*	2	1	1	1
300....	4801.22	4801.21	*Cr-Gd*	1	1	5-3	3-3
300....	4802.82	....	...	...	1	...	...
300....	4804.02	....	...	...	0	...	...
800....	4805.31	4805.28	*Ti*	3	5	...	L4
300....	4806.63	....	...	...	0	...	...
300....	4807.08	....	...	...	0	...	...
300....	4807.40	....	...	...	0	...	...
300....	4808.68	4808.73	*Ti*	00	1	2	2
300....	4809.24	4809.20	*La-*	(2) 0	0	4-	3-
400....	4810.62	4810.72	*Zn*	3	2d?	200	500
300....	4811.48	(4811.49)	*Nd*	...	1	5	5
300....	4812.25	4812.20	*Ti, Sr*	00	1d	1, 20	2, 10
250....	4813.28	4813.30	–	0	0	...	...
300....	4813.66	4813.66	*Co*	1	2	8	10
250....	4814.02	....	...	...	0	...	...
300....	4814.74	4814.78	*Ni*	00	1	1	1
300....	4815.92	(4815.90)	*Zr-Sa*	...	1d	10-6	3-4
250....	4816.60	....	...	...	0	...	...
400....	4817.89	4817.99	*Ni*	2	1N	2	1
350....	4820.57	4820.59	*Ti-Er-Nd*	1	2	8-8-4	3-4-3
250....	4821.81	....	...	...	0	...	...
750....	4823.63	4823.70	*Mn*	5	5	30	10
750....	4824.27	4824.32	*Cr-La*	3	5	2-5	L10-4
500....	4825.65	4825.66	*Nd*	(3) 0	3	8	8
300....	4827.07	4827.03	*Mn-La*	000	0	1-1	1-1
300....	4827.68	4827.64	*V*	000	1d	8	5
250....	4828.55	....	...	...	0	...	...
350....	4829.29	4829.35	*Ni, Cr*	(2) 5	2d	10, 5	3, 3
400....	4831.26	4831.36	*Ni-Er*	3	1	5-5	3-3

TABLE I—*Continued*

Height of Chromosphere	Wave-Lengths		Substance	Intensities			
	Chromosphere	Rowland		Rowland	Chromosphere	Arc	Spark
km							
300....	4832.72	{4832.62	*V*	00 }	1d	3	3
		{4832.90	*Fe-Ni*	3 }		1-3	-1
400....	{4836.13	4836.06	*Fe, Nd*	2	2	1, 3	-, 2
300....	{4836.99	4837.04	*Cr*	00	1	2	1
350....	4838.72	4838.74	*Ni, Fe*	(^{2}) 3	1	3, 1	2, -
300....	4839.73	4839.73	*Fe*	3	1	1	1
300....	4840.42	4840.45	*Co*	2	2	10	10
350....	4841.00	4841.07	*Ti*	3	1	10	4
300....	4843.01	4842.98	*Fe*	1	0	...	...
300....	4843.46	4843.42	*Fe-Co*	(^{2}) 3	1d	1-3	1-
350....	4844.28	4844.21	*Ti-Fe*	1	0	1-	1-
350....	4848.56	4848.48	*Cr-Ti*	(^{2}) 2	2d	1-	L8-
350....	4849.33	4849.36	-	0	2	...	...
350....	4851.67	4851.69	*V*	1	1	10	8
300....	4852.77	4852.74	*Ni*	2	1	2	1
350....	4855.00	4855.06	*Y*	1	3?	10	L30
300....	4855.55	4855.60	*Ni*	3	1	10	3
300....	4856.18	4856.20	*Ti*	1	0	8	5
350....	4857.51	4857.58	*Ni*	1	1	3	1
350....	4859.20	4859.22	*Nd*	000	1	5	5
350....	4859.95	4859.93	*Fe-Y*	4	1	6-8	2-3
8000....	4861.90	4861.53	*Hβ*	30	100	...	...
350....	4864.50	4864.50	*Cr*	1	1	...	L5
300....	4864.89	4864.92	*V*	0	1	10	8
350....	4865.70	4865.80	*Ti*	1	0	...	1
350....	4866.60	....	...	...	1N	...	...
350....	4868.20	4868.19	*Co, Ti*	(^{2}) 2	2d	10, 8	10, 3
300....	4870.37	4870.32	*Ti*	1	0	8	3
350....	4870.98	4871.00	*Ni, Cr*	3	0	3, 3	1, 2
400....	4871.54	4871.51	*Fe*	5	3	8	4
400....	4872.35	4872.33	*Fe*	4	3	8	3
400....	4873.63	4873.63	*Ni*	2	1	8	2
400....	4874.16	4874.20	*Ti*	0	1	...	L3
350....	4875.69	4875.67	*V*	1	1	10	10
350....	4876.59	4876.59	*Cr*	1	2	...	L5
350....	4877.75	4877.77	-	0	0	...	...
500....	4878.36	4878.37	*Cr, Fe*	(^{2}) 7	3d	20, 6	8, 2
400....	4881.75	4881.74	*V*	1N	2	10	10
350....	4882.36	4882.34	*Fe*	3	1	1	1
600....	4883.93	4883.87	*Y*	2	6	15	L50
300....	4884.84	4884.78	-	0	1	...	...
300....	4885.25	4885.26	*Ti*	2	1	10	5
300....	4885.61	4885.62	*Fe*	3	0	1	1
300....	4886.18	4886.13	*Cr*	00	0	1	1
350....	4886.55	4886.52	*Fe-Er*	3	1	1-3	1-1
350....	4887.29	4887.28	*Cr-Ni-Fe*	(^{2}) 4	2d	3-2-1	3-1-
350....	4888.79	4888.82	*Fe*	2	1	1	1
400....	4889.28	4889.23	*Fe-*	(^{2}) 5	2	1-	1-
600....	4890.96	4890.95	*Fe*	6	5	8	4
600....	4891.72	4891.68	*Fe*	8	6	10	5
300....	4893.10	4893.03	*Fe*	1	1	1	...

TABLE I—*Continued*

Height of Chromosphere	Wave-Lengths		Substance	Intensities			
	Chromosphere	Rowland		Rowland	Chromosphere	Arc	Spark
km							
300....	4894.03	4894.00	–	00	1d?	...	...
250....	4894.78	4894.74	–	00	0	...	...
300....	4896.68	4896.62	*Fe*	1	0	...	...
600....	4900.32	4900.30	*Y*	2	10	10	L30
250....	4901.83	4901.81	*V*	00	0	3	5
300....	4902.46	4902.42	–	00	1N	...	...
350....	4903.47	4903.50	*Fe*	5	2d	5	2
350....	4904.56	4904.60	*V, Ni*	3	2	5, 10	8, 3
300....	4905.33	4905.31	*La*	0	1	1	...
300....	4906.28	4906.32	*Y*	000	0	3	2
300....	4907.68	4907.68	*Fe, Eu*	0000	0d?	1-8	–2
300....	4908.20	4908.21	–	0N	0	...	...
300....	4908.73	4908.73	*Co*–	(?) 0	0	1–	...
300....	4909.44	4909.49	*Ti, Fe*	(?) 2	0d	1, 1	1–
350....	4910.05	....	...	...	0	...	...
350....	4910.50	4910.50	*Fe*	2	1	1	...
350....	4910.79	4910.75	*Fe*	2	1	1	1
350....	4911.35	4911.37	*Ti*	1	1	...	L5
300....	4912.15	4912.20	*Ni*	1	0	3	1
250....	4913.38	4913.36	–	(?) 0	0	...	...
300....	4913.76	4913.80	*Ti*	2	1	10	3
300....	4914.17	4914.15	*Ni*	2	1	3	1
350....	4917.42	4917.41	*Fe*	2	1	1	...
350....	4918.55	4918.54	*Ni*	2	2	3	2
400....	4919.20	4919.17	*Fe*	6	3	10	4
350....	4920.02	4920.05	*Ti*	00	1	4	2
500....	4920.68	4920.68	*Fe*	10	4	15	8
400....	4921.10	4921.15	*La*	0	1	5	8
1500....	4922.19	(4922.10)	*He*	...	3d	...	...
1000....	4924.14	4924.11	*Fe*	5	20	...	L8
350....	4925.01	4924.96	*Zn, Fe*	3	0	–, 2	500, 1
350....	4925.78	4925.75	*Ni-V*	1	1	3-3	1-1
300....	4927.18	....	...	...	0	...	...
300....	4927.53	4927.60	*Fe*	1	0	...	...
350....	4928.05	4928.05	*Fe*	2	1	1	...
350....	4928.55	4928.51	*Ti*	0	0	5	3
300....	4930.55	4930.49	*Fe*	2	0N	1	1
350....	4933.49	4933.51	*Fe*	2	1	1	1
750....	4934.26	4934.25	*Ba*	7d	12	100	300
300....	4935.95	4936.02	*Ni*	2	0	5	2
300....	4936.42	4936.51	*Cr*	1	0	3	1
300....	4937.59	4937.52	*Ni*	3	0	5	1
300....	4938.30	4938.35	*Fe*	2	0	1	1
350....	4939.02	4938.98	*Fe*	4	0	3	1
300....	4939.42	4939.42	*Fe*	2	0	1	...
350....	4939.83	4939.87	*Fe*	3	1	2	1
300....	4940.35	....	...	...	0	...	...
350....	4942.67	4942.66	*Cr*	2	0	3	1
300....	4944.47	4944.47	*Er*	00	0	3	1
300....	4945.72	4945.72	*Ni-Fe*	(?) 2	1d	2–	...
350....	4946.59	4946.57	*Fe-La*	3	2	2-2	1-1

TABLE I—*Continued*

Height of Chromosphere	Wave-Lengths		Substance	Intensities			
	Chromosphere	Rowland		Rowland	Chromosphere	Arc	Spark
km							
300....	4949.16	....	...	...	0	...	...
350....	4950.27	4950.29	*Fe*	2	1	1	...
350....	4952.32	....	...	...	0	...	...
350....	4952.81	4952.82	–	2	0	...	...
300....	4953.38	4953.39	*Ni*	2	1	3	1
350....	4954.87	4954.92	*Cr-Fe*	(²) 3	1d	3–	2–
500....	4957.68	4957.67	*Fe*	(²) 13	8d	15	11
300....	4958.41	4958.43	*Ti*	00	0	1	1
400....	4959.25	(4959.28)	*Nd*	...	1d	4	2
250....	{4961.68	....	...	...	0	...	...
250....	{4962.75	4962.75	*Eu*	2	0	3	2
250....	{4963.64	....	...	...	0	...	...
250....	4964.88	4964.90	*Ti*	000	0	1	1
250....	4965.40	4965.35	*Ni*	0	0	1	...
350....	4966.33	4966.27	*Fe-V*	4	1	2-2	2-1
350....	4968.03	4968.08	*Fe*	3	2	1	...
350....	4968.80	4968.84	*Fe, Ti*	(²) 2	2	–1	–1
350....	4970.05	4970.10	*Fe*	3	2	1	...
300....	4970 59	4970.67	*Fe-La*	1	1	–3	–2
300....	4971.53	4971.53	*Ni*	1	1	3	1
400....	4973.20	4973.28	*Ti-Fe*	4	2d	2-1	2-1
300....	4974.60	4974.64	*C*	0000	0d	...	...
300....	4975.60	4975.56	*Ti-Fe*	(²) 0	1d	3–	3–
300....	4976.37	4976.44	*Ni*	(²) 1	0	2	...
250....	4978.38	4978.37	*Ti*	00	0	2	2
300....	4978.76	4978.78	*Fe*	3	1	1	1
300....	4979.34	4979.39	*C*	000	0	...	...
250....	4979.80	4979.77	*Fe*	00	0	...	...
300....	4980.35	4980.35	*Ni*	4	1	10	2
350....	4981.89	4981.91	*Ti*	4	2	20	10
300....	4982.69	4982.68	*Fe*	4	0d	3	1
300....	4983.56	{4983.43	*Fe*	3	} 1d?	{ 1	1
		{4983.64	*C*	0000		...	...
350....	4984.14	4984.14	*Ni-Fe*	(²) 5	2d	10-2	2-1
350....	4985.47	4985.43	*Fe*	3	1	1	1
350....	4985.77	4985.73	*Fe*	3	1	1	1
250....	4986.46	4986.40	*Fe*	1	0	...	...
300....	4986.80	....	...	...	0	...	...
300....	4988.31	4988.31	*C*	000	1	...	...
350....	4989.17	4989.13	*Fe*	2	2	1	...
400....	4991.29	4991.25	*Ti*	3	3	20	10
400....	4993.65	4993.70	–	(²) 1	1d?	...	...
500....	4994.25	4994.32	*Fe*	3	1	2	1
250....	4995.70	4995.71	–	(²) 0	0N	...	...
350....	{4996.85	....	...	...	0	...	...
350....	{4997.29	4997.28	*Ti*	0	1	3	1
350....	4998.40	4998.41	*Ni*	1	0	2	1
400....	4999.67	4999.69	*Ti-La*	3	2d	20-5	10-3
350....	5000.50	5000.53	*Ni*	2	0	...	1
350....	5001.22	5001.16	*Ti-C*	0	0	3	2
400....	5002.02	5002.04	*Fe*	5	3	4	2

TABLE I—*Continued*

Height of Chromosphere	Wave-Lengths		Substance	Intensities			
	Chromosphere	Rowland		Rowland	Chromosphere	Arc	Spark
km							
300....	5002.83	(5002.80)	*V-Ce-C*	2	od	3-1-	3-1-
350....	5003.90	5003.92	*Ni*	0	1d	2	...
350....	5005.39	5005.35	*Mn*	0	0	...	...
400....	5005.86	5005.90	*Fe*	4	2	2	1
400....	5006.31	5006.31	*Fe*	5	2	5	2
350....	5007.41	5007.42	*Ti-Fe*	5d	2d	20-1	10-2
350....	5009.90	5009.83	*Ti*	00	0	2	1
400....	5010.43	5010.40	*Ti*	00	1	...	1
500....	5011.12	5011.12	*Ni*	0	1	3	...
350....	{5011.67	....	*C*	...	0	...	...
500....	{5012.25	5012.25	*Fe*	4	2	5	2
350....	{5012.67	5012.63	*Ni*	1	0	4	1
350....	5013.32	5013.33	*Ti-Cr*	(²) 3	1	4-	3-
350....	5013.85	5013.87	*Ti*	0	1	...	1
350....	5014.43	5014.42	*Ti-Ni*	(²) 5	1	20-3	8-
350....	5015.16	5015.12	*Fe*	3	0	2	1
1600....	5015.86	(5015.73)	*He*	...	2	...	...
350....	5016.32	5016.34	*Ti*	2	0	10	5
600....	5017.20	....	...	...	0	...	...
350....	5017.70	5017.76	*Ni*	3	0	8	2
1200....	5018.61	5018.63	*Fe*	4	15	1	L7
350....	5019.94	5019.91	*V-La-*	00	0	1-1	3-
400....	5020.20	5020.21	*Ti*	2	1	10	5
300....	5020.96	5021.00	–	00	0	...	...
300....	5021.85	5021.87	*C*	000	0	...	...
350....	5022.44	5022.41	*Fe*	3	2	1	1
500....	5023.05	5023.05	*Ti*	2	2	10	5
300....	5023.37	5023.37	*Fe?*	0	0	...	...
300....	5023.72	5023.67	*Fe, Sa*	0	0	-2	-1
300....	{5024.30	(5024.34)	*C*	...	0	...	...
300....	{5025.00	5025.03	*Ti*	3	1	10	3
300....	{5025.70	5025.75	*Ti*	1	1	10	3
350....	{5027.36	5027.30	*Fe*	3	2	1	1
300....	{5028.13	5028.18	*Fe-C*	(²) 3	od	...	...
300....	5029.79	5029.80	*Fe*	1	1	...	...
600....	5031.18	5031.20	*Sc-C*	3	5	5	4
300....	5032.10	5032.09	–	00	0	...	...
300....	5032.98	5032.91	*Ni*	00	0	2	...
300....	5033.76	5033.77	*C-Eu*	(²) 0	0	-3	-1
500....	5035.58	5035.54	*Ni*	5	1	20	3
500....	{5036.09	{5036.12	*Ti-Ni*	(²) 5	1	10-5	8-
400....	{5036.43	{5036.45	*Fe*	0	0	...	...
400....	{5036.67	{5036.64	*Ti*	2	0	10	8
300....	5037.93	5037.93	*Ce-C*	(²) 0	0	2-	1-
500....	5038.59	5038.58	*Ti*	2	2	10	8
350....	5039.40	5039.43	*Fe*	3	0	...	...
400....	5040.16	5040.14	*Ti*	3	1	10	3
500....	5041.15	5041.18	*Fe-Ni*	(²) 7	2	2-2	1-
500....	5041.89	5041.89	*Ca, Fe*	(²) 6	3d	20, 3	2, 1
400....	5042.36	5042.37	*Ni*	1	1	5	...
300....	5043.76	5043.76	*Ti*	00	0	2	1

TABLE I—*Continued*

Height of Chromo-sphere	Wave-Lengths		Substance	Intensities			
	Chromo-sphere	Rowland		Rowland	Chromo-sphere	Arc	Spark
km							
300....	5044.43	5044.39	*Ni, Co-Fe*	3	1	...	...
300....	5045.56	5045.52	*Ti-C*	(²) 0	0	...	...
350....	5048.21	5048.24	*Ni*	0	0	2	...
400....	5048.64	5048.61	*Fe*	3	1	...	...
400....	5049.06	5049.04	*Ni*	2	1	5	1
600....	5050.03	5050.01	*Fe*	6	2	4	2
300....	5050.88	5050.92	*C*	000	0	...	...
600....	5051.84	5051.82	*Fe-V*	4	2d	3-2	1-2
400....	5053.09	5053.06	*Ti*	0	1d	2	2
300....	5055.10	....	...	...	0	...	...
350....	5056.30	5056.31	*C*	000	0N	...	...
300....	5057.00	5057.02	*Fe*	1	0	...	...
300....	5057.99	5058.02	–	000	0	...	...
400....	5060.25	5060.26	*Fe*	3	1	1	...
300....	5062.29	5062.28	*Ti*	0	0	2	1
300....	5063.33	5063.36	*C*	00	0	...	...
450....	5064.74	5064.72	*Ti*	(²) 3	1	11	6
500....	5065.26	5065.26	*Fe–*	(³) 6	2	7	...
300....	5066.26	....	...	...	0	...	...
300....	5067.39	5067.34	*Fe*	3	1	1	...
300....	5067.88	5067.87	*Cr*	0	0	...	...
500....	5068.91	5068.94	*Fe-C*	5	1	4–	1–
400....	5070.18	5070.16	*C–*	00	2N	...	...
300....	5070.81	....	...	...	0	...	...
300....	5071.66	5071.67	*Ti*	0	1	3	2
400....	{5072.21	{5072.26	*Fe*	3	2	1	...
400....	{5072.52	{5072.48	*Ti*	0	0	...	L3
300....	{5072.81	{5072.85	*Fe*	2	0	1	...
300....	5073.60	5073.64	*C*	00	0	...	...
450....	5074.93	5074.93	*Fe*	5	2	8	1
300....	5075.69	....	...	...	0	...	...
400....	5076.40	5076.45	*Fe*	3	1	1	...
400....	5076.78	5076.81	*Nd-C*	0	0	3–	2–
500....	5079.27	5079.30	*Fe*	(²) 7	3d	5	2
400....	5080.02	5079.97	*Fe-Ni*	(²) 5	2d	2-2	1–
400....	5080.76	5080.71	*Ni*	4	1	8	3
400....	5081.26	5081.29	*Ni*	3	1	8	3
300....	5081.90	5081.85	*Sc-C*	(²) 0	0	...	2–
300....	5082.74	....	...	...	1d?	...	...
400....	5083.54	5083.52	*Fe*	4	2	3	1
400....	{5084.30	5084.28	*Ni*	3	2	5	3
300....	{5084.71	5084.73	–	000	0	...	...
300....	5086.16	....	...	...	0	...	...
350....	5087.21	5087.24	*Ti*	0	0	3	2
500....	5087.62	5087.60	*Y*	1	3	10	10
300....	5088.45	5088.52	*Y-Ni-C*	(²) 1	0d	...	...
450....	5089.39	5089.39	*C*	000Nd?	2d?	...	...
450....	5090.96	5090.95	*Fe-C*	5	2	2	1
300....	5092.62	(5092.60)	*C*	...	1d	...	...
300....	5095.34	5095.35	*C–*	00	0d	...	...
300....	5096.08	5096.03	...	000	0	...	...

TABLE I—*Continued*

Height of Chromo-sphere	Wave-Lengths		Substance	Intensities			
	Chromo-sphere	Rowland		Rowland	Chromo-sphere	Arc	Spark
km							
300....	5096.82	5096.91	*C*	000	0	...	...
400....	5097.18	5097.17	*Cr-Fe*	3	1	-2	L2-1
300....	5098.29	5098.30	*C*	00N	0.	...	...
400....	5098.89	5098.88	*Fe*	3	1	4	1
400....	5099.39	5099.42	*Ni-Fe*	(²) 1	0	4-1	1-
400....	5100.03	5100.11	*Ni*	2	1	8	1
350....	5100.99	5101.03	*C*	000	0N	...	...
300....	5103.79	....	...	...	0	...	...
300....	5104.40	5104.39	*Fe-*	(³) 1	0N	...	...
350....	{5105.42	5105.38	*Y-Nd*	(³) 0	0	2-2	3-1
400....	{5105.70	5105.72	*Fe-Cu-Co*	4	2	1-50-3	-20-
400....	5106.61	5106.62	*C*	000	1N	...	...
500....	5107.75	5107.72	*Fe*	(²) 8	3d	4	2
400....	5109.76	5109.83	*Fe*	2	0N	1	...
600....	5110.63	5110.57	*Fe*	5d	2	3	1
300....	5110.91	5110.94	*Cr-C*	00	0	1	...
300....	5111.50	5111.48	*C*	(²) 00	0	...	...
350....	5111.83	5111.80	*C*	000	1	...	...
300....	5112.41	5112.46	-	000	1	...	...
300....	5112.90	5112.88	-	(²) 00	0	...	...
350....	{5113.26	5113.25	*Cr-C*	(²) 0	1	1-	...
350....	{5113.64	5113.62	*Ti*	0	1	4	2
350....	5114.62	5114.56	*La-C*	(²) 00Nd?	1d	4-	3-
400....	5115.58	5115.57	*Ni*	2	2	10	2
359....	5116.34	5116.36	-	0000	0	...	...
350....	{5116.84	5116.85	*C*	0000	1	...	...
350....	{5117.10	5117.07	-	000	1	...	...
350....	{5118.14	5118.11	*Mn, C*	00	1	2, -	1, -
400....	{5118.34	5118.35	*C*	0000	1	...	9
350....	{5119.35	5119.29	*Y-C*	00	1	3-	3-
300....	{5119.65	....	...	...	0	...	...
350....	5120.60	5120.59	*Ti*	0	1d	5	4
350....	5121.77	5121.80	*Fe-Ni-C*	(²) 3	1d	2-3-	...
300....	5122.50	5122.48	*C*	0000	0	...	...
350....	5123.14	5123.18	*La*	000	2	4	3
400....	5123.35	5123.39	*Y*	0	1	4	4
400....	5123.90	5123.90	*Fe*	3	2	3	1
350....	5125.30	5125.30	*Fe*	3	2	5	1
300....	5126.18	5126.17	*C*	0000	1	...	...
300....	5126.40	5126.37	*Fe-Co*	2	1	1-3	...
300....	5127.52	5127.53	*Fe-Ti*	3	0	2-1	1-1
300....	5127.99	5128.05	*C*	0000	0	...	...
300....	{5128.53	5128.49	*C*	0000	0	...	...
300....	{5128.74	5128.73	*V-C*	(³) 00	0	8-	10-
500....	5129.41	5129.42	*Ti-Ni*	(²) 5	3d	1-10	L8-1
350....	5130.44	5130.46	*Ni-C*	(²) 0	0	...	...
350....	5130.73	5130.76	*Nd-C*	000	2	5-	4-
350....	{5131.66	5131.64	*Fe-C*	2	2	2	...
400....	{5131.92	5131.94	*Ni-C*	1	2	4-	...
350....	5132.72	5132.72	*C*	(³) 0	1d	...	...
400....	5133.82	5133.87	*Fe-C*	4	3	15	2

TABLE I—*Continued*

Height of Chromosphere	Wave-Lengths: Chromosphere	Wave-Lengths: Rowland	Substance	Intensities: Rowland	Intensities: Chromosphere	Intensities: Arc	Intensities: Spark
km							
350....	5134.64	5134.68	*C*	(3) 0	0d	...	...
300....	5135.35	5135.36	–	0000	0	...	...
300....	5135.82	5135.82	*C*	(2) 00	0N	...	...
300....	5137.23	5137.25	*Ni*	3	1	8	1
350....	5137.59	5137.56	*Fe*	3	2	10	1
350....	5138.55	5138.52	*V-C*	0000	1	8–	10–
350....	5139.42	5139.43	*Fe-C*	4	0	3–	2–
500....	5139.60	5139.64	*Fe-V*	4	4	8-3	3-3
300....	5139.82	5139.82	*Cr*	00	0	2	...
350....	5141.17	5141.19	–	0000	0	...	...
350....	5141.40	5141.44	*C*	(2) 00	0	...	...
350....	5141.92	5141.92	*Fe*	3	1	2	1
500....	5142.67	5142.69	*Fe*	4d?	3	2	1
400....	5143.05	5143.05	*Ni-Fe-C*	5	2	15-2-	1–
350....	5144.74	5144.76	*C–*	000	0d	...	...
350....	5145.51	5145.56	*Ti-La-C*	(2) 1	1N	5-3-	3-1-
500....	5146.48	5146.29	*C*	00	3d	...	...
		5146.66	*Ni-C*	3		20	2–
500....	5147.78	5147.79	*C-Ti*	(3) 1	2	...	...
500....	5148.30	5148.33	*Fe*	(2) 5	2	5	1
400....	5149.30	5149.27	*C*	000	1	...	...
350....	5150.35	5150.36	*C–*	00	0	...	...
400....	5150.89	5150.74	*C*	000	2d	...	...
		5151.02	*Fe*	4		2	1
400....	5152.05	5152.09	*Fe-C*	3	1	2–	1–
400....	5152.38	5152.36	*Ti*	0	0	5	2
400....	5153.30	5153.34	*C*	0000	1	...	...
500....	5154.27	5154.24	*Ti-Co*	2	3	1-3	L4–
400....	5155.68	5155.70	*Ni-C*	(3) 3	2d	13–	1–
400....	5156.70	5156.73	*C*	0000	1	...	...
350....	5157.78	5157.78	*C*	000	1	...	...
350....	5158.12	5158.18	*Ni*	00	0	2	...
400....	5158.70	5158.70	*C*	000	1	...	...
400....	5159.60	5159.63	*C*	000	0	...	...
350....	5159.91	5159.95	–	0000	0	...	...
350....	5160.46	5160.42	*C–*	00N	1	...	...
350....	5161.20	5161.19	*C*	000	1	...	...
350....	5161.86	5161.85	*C*	0000	1	...	...
400....	5162.50	5162.45	*Fe, C*	5	2	8, –	1, –
350....	5163.07	5163.07	*C*	000	0	...	...
350....	5163.60	5163.58	*C*	000	0	...	...
350....	5164.43	5164.40	*C*	000	0	...	...
400....	5164.88	5164.90	*C*	000	0	...	...
500....	5165.35	5165.30	*C*	0000	2	...	...
		5165.42*	*C*	0000			
500....	5166.43	5166.45	*Cr-Fe*	3	1	2-2	1-1
700....	5167.54	5167.50	*Mg*	15	12	50	20
		5167.68	*Fe*	5		20	4
300....	5167.94	5167.89	...	00	0	...	...
700....	5169.18	5169.16	*Fe*	(2) 7	15	2	L6

* Head of carbon band.

TABLE I—*Continued*

Height of Chromosphere	Wave-Lengths		Substance	Intensities			
	Chromosphere	Rowland		Rowland	Chromosphere	Arc	Spark
km							
300....	5170.87	5170.94	*Fe*	0	0d	1	...
600....	5171.75	5171.78	*Fe*	6	2	10	2
1000....	5172.82	5172.86	*Mg*	20	20	50	30
500....	5173.92	5173.92	*Ti*	2	2	15	5
300....	5175.58	5175.58	–	000	0	...	...
500....	5176.76	5176.74	*Ni*	1	1	8	1
300....	5177.62	5177.58	*Cr-Co*	00	0	1-1	1–
250....	5178.40	....	...	...	0	...	...
300....	5180.28	5180.23	*Fe*	1	0	1	...
250....	5181.84	....	...	...	0	...	...
1200....	5183.74	5183.79	*Mg*	30	25	100	100
250....	5184.47	5184.44	*Fe*	2	0	1	...
250....	5185.10	....	...	...	0	...	...
500....	5185.97	5186.07	*Ti*	2	2	...	L5
350....	5186.84	....	...	...	0	...	...
300....	5187.40	....	...	...	0	...	...
400....	5187.92	....	...	...	0	...	...
750....	5188.85	5188.86	*Ti*	3	4	2	L10
500....	5191.66	5191.63	*Fe*	4	3	10	2
350....	5192.10	5192.15	*Cr*	00	0	2	1
500....	{5192.60	5192.52	*Fe-Nd*	5	3	10-6	2-2
300....	{5193.14	5193.14	*Ti*	2	0	20	8
300....	5194.19	5194.22	*Ti*	000	0	2	1
400....	5195.15	5195.11	*Fe*	4	3	5	1
350....	5195.65	5195.65	*Fe-V*	2	1	4-3	1-3
300....	5196.26	5196.23	*Fe*	1	0	1	...
350....	5196.63	5196.61	*Cr*	0	1	2	1
500....	5197.73	5197.74	*Fe?*	2	4	1	1
300....	5198.11	5198.11	...	0	0	...	...
400....	5198.90	5198.89	*Fe*	3	1	3	1
400....	5200.45	5200.51	*V-Cr*	([2]) 1	2d	10-1	8-1
300....	5201.31	5201.26	*Ti*	000	1	2	1
400....	5202.43	5202.49	*Fe–*	([2]) 6	2d	5	1
300....	5203.30	....	...	...	0	...	...
500....	5204.70	5204.71	*Cr-Fe*	([2]) 8	3d	20-2	10–
300....	5205.18	....	...	...	0	...	...
600....	5206.06	{5205.90 {5206.22	*Y* *Cr-Ti*	0} 5}	6d	{10 {30-2	10 15-2
300....	5207.72	5207.79	–	000	0	...	...
500....	5208.54	5208.60	*Cr*	5	5	30	20
250....	5209.61	....	...	...	0	...	...
300....	5210.48	5210.56	*Ti*	3	1d	20	10
250....	5211.53	....	...	...	0	...	...
250....	5212.34	5212.40	*V, Cr*	000	0	1, 1	1, –
250....	5212.90	5212.86	*Co*	000	0	8	1
300....	5215.35	5215.35	*Fe*	3	1	6	1
350....	5216.47	5216.44	*Fe*	3	2	6	1
300....	5217.56	5217.55	*Fe*	3	1	5	1
300....	5218.31	5218.27	*Fe, Cu*	([2]) 1	1d	1, 200	–, 200
250....	5219.66	(5219.68)	*Ti-Gd*	...	0	3-3	2-1
250....	5220.28	5220.36	*Ni*	0	0d	5	...

TABLE I—*Continued*

Height of Chromosphere	Wave-Lengths: Chromosphere	Wave-Lengths: Rowland	Substance	Intensities: Rowland	Intensities: Chromosphere	Intensities: Arc	Intensities: Spark
km							
250....	5221.20	5221.20	*Cr*	00	0	1	...
250....	5222.47	(5222.50)	*Sr*	...	0	20	2
250....	5223.33	5223.35	*Fe*	0	0	1	...
250....	5224.35	5224.29	*Ti-V-Cr*	(2) 1	0	4-5-1	2–
300....	5224.98	5225.03	*Cr-Ti*	(3) 1	0d	5-2	1-1
300....	5225.63	5225.70	*Fe*	2	0	1	...
500....	5226.69	5226.71	*Ti*	2	4	1	L10
500....	5227.20	5227.26	*Fe-Cr*	(2) 8	3	13-1	6–
250....	5227.92	5227.90	–	000	0	...	...
300....	5228.56	5228.55	*Fe*	1	1	1	...
400....	5230.04	5230.03	*Fe*	4	2	5	1
300....	5230.54	......	...	...	0	...	...
400....	5233.15	5233.12	*Fe*	7	2	20	5
500....	5234.80	5234.79	–	2	5	...	...
250....	5235.59	5235.60	*Ni, Fe*	(2) 1	1	4, 2	–, 1
250....	5236.38	5236.37	*Fe*	0	0	1	...
250....	5237.05	....	...	...	0	...	...
350....	5237.47	5237.49	*Cr*	1	2	1	L7
250....	5238.70	5238.74	*Ti, Sr*	000	0	2, 30	2, 3
250....	5239.10	5239.14	*Cr*	00	0	1	...
350....	5239.95	5239.99	*Sc, Nd*	1	2	3, 3	2, 1
250....	5241.04	5241.04	*V*	000	0	3	5
250....	5241.88	....	...	...	0	...	...
250....	5242.66	5242.66	*Fe*	2	1	3	1
250....	5243.98	5243.95	*Fe*	1	0	1	...
250....	5246.88	5246.84	*Ti–*	(2) 00	0	2–	1–
300....	5247.26	5247.23	*Fe*	1	0	1	...
300....	5247.72	5247.74	*Cr*	2	0	8	2
350....	5249.68	(5249.69)	*Nd*	...	2N	8	4
350....	5250.33	5250.38	*Fe*	2	1	1	...
350....	5250.82	5250.82	*Fe*	3	2	3	1
250....	5252.15	5252.15	*Fe*	0	0	1	...
250....	5252.61	....	...	...	0	...	...
250....	5253.70	5253.63	*Fe*	2	0	2	1
350....	5254.93	....	...	...	1	...	...
350....	5255.32	5255.25	*Fe, Cr-Mn*	(3) 4	1N	1. 5-4	-, 2-2
300....	5257.00	5257.10	*Sr*	00	0	50	3
250....	5257.96	5257.90	*Co–*	(2) 0	0	5–	1–
250....	5259.48	....	...	...	1	...	...
250....	5260.13	5260.14	*Ti*	000	0	1	1
300....	5261.86	5261.88	*Ca-Cr*	3	2	10-1	3-1
300....	5262.37	5262.39	*Ca-Ti*	(2) 4	2	10–	3-1
250....	5263.08	5263.06	...	00	0	...	...
350....	5263.56	5263.49	*Fe*	4	1	5	1
300....	5264.04	5264.04	*Fe*	0	0	1	...
350....	5264.37	5264.37	*Cr, Ca*	(2) 7	1	8, 15	3, 3
350....	5264.93	5264.98	*Co*	0	1	1	...
350....	5265.87	5265.85	*Ca-Cr-Ti*	(3) 6	1d	20-3-3	5-2-3
350....	5266.77	5266.74	*Fe*	6	2	15	3
250....	5267.70	5267.74	*V–*	(2) 00	0	...	1

TABLE I—*Continued*

Height of Chromo-sphere	Wave-Lengths		Substance	Intensities			
	Chromo-sphere	Rowland		Rowland	Chromo-sphere	Arc	Spark
km							
300....	5268.61	5268.61	*Ni-Co*	(2) 1	1N	4-4	...
500....	5269.72	5269.72	*Fe*	8d?	8	20	8
500....	5270.49	5270.51	*Fe-Ca*	(2) 7	6	15-30	4-10
300....	5271.46	5271.46	*La*	00	0	4	1
350....	5272.17	5272.17	*Co-Eu*	00	1	2-4	1-1
350....	5273.61	5273.56	*Fe-Nd-Cr*	2	3d	2-5-1	1-3-
300....	5274.39	5274.41	*Ce*	00	1	5	3
300....	5275.18	5275.15	*Fe*	0	1	1	...
300....	5275.42	5275.45	–	1	1	...	...
500....	5276.16	5276.15	*Cr-Fe-*	(3) 6	10	5-1	1-1
250....	5277.48	5277.48	*Zr*	00	0	1	1
300....	5280.05	5280.05	*Fe*	0	0	1	...
300....	5280.62	5280.63	*Co-Fe*	1	1	8–	...
350....	5281.97	5281.97	*Fe*	5	2	8	2
300....	5282.45	5282.49	*Ti-*	(2) 0	0N	2–	1–
350....	5283.81	5283.80	*Fe*	6	2	10	2
400....	5284.29	5284.28	–	1	3	...	...
250....	5285.27	5285.30	*Ni*	0	0	...	...
300....	5288.81	5288.77	*Fe-Ti*	(2) 2	1d	1-1	-1
250....	5289.72	5289.68	*Mn*	000	0	1	...
250....	5292.65	....	...	...	1	...	...
250....	5293.32	5293.34	*Nd*	00	2	10	5
250....	5295.47	5295.48	*Fe*	0	0	...	...
300....	5296.86	5296.87	*Cr*	3	1	4	3
300....	5297.57	5297.56	*Cr*	2	1	2	2
350....	5298.45	5298.46	*Cr*	4	2	4	4
250....	5298.99	5298.96	*Fe-Mn*	0	0	1-1	1–
250....	5300.15	5300.15	*Ti*	00	0	1	1
250....	5300.99	5300.93	*Cr*	2	0	4	2
350....	5302.44	5302.48	*Fe-Nd*	5	2d	8-3	2-2
300....	5303.56	5303.52	*V-La*	(2) 1	1N	1-3	2-3
250....	5306.03	5306.04	*Cr*	0	0	...	1
400....	5307.57	5307.54	*Fe*	3	2	2	1
250....	5308.66	5308.60	*Cr*	0	0	...	L2
250....	5312.57	5312.55	...	(2) 0	0	...	...
250....	5313.02	5313.03	*Cr*	0	0	...	...
250....	5313.74	5313.76	*Cr*	1	1	...	1
250....	5314.41	5314.42	–	000N	0	...	...
250....	5315.24	5315.25	*Fe*	1	0	1	...
850....	5316.83	5316.86	*Fe-Co*	(3) 6	12	-4	L3–
250....	5318.48	5318.53	*Sc*	00	0N	1	...
250....	5318.95	5318.96	*Cr*	0	0	2	1
300....	5320.04	5320.07	*Nd-Fe*	(2) 1	1d?	10-1	4
300....	5321.26	5321.29	*Fe*	2	1	1	...
300....	5322.25	5322.23	*Fe*	3	1	1	...
300....	5323.05	....	...	...	1	...	...
400....	5324.40	5324.37	*Fe*	7	4	20	5
400....	5325.76	5325.74	–	2	3	...	...
250....	5326.63	5326.61	–	(2) 00	0	...	...
500....	5328.20	5328.24	*Fe*	8d?	8	15	6
500....	5328.61	5328.65	*Fe, Cr*	(3) 6	6	8, 10	2, 10

TABLE I—*Continued*

Height of Chromosphere	Wave-Lengths: Chromosphere	Wave-Lengths: Rowland	Substance	Intensities: Rowland	Intensities: Chromosphere	Intensities: Arc	Intensities: Spark
km							
350....	5329.36	5329.33	*Cr*	3	0	3	1
350....	5330.14	5330.18	*Fe, Sr*	2	1	2, 20	–, 1
250....	5330.78	5330.75	*Ce*	000	0	4	2
250....	5331.56	5331.64	*Co*	00d	0	4	...
350....	5333.02	5332.98	*Fe, Co.*	([2]) 5	2d	1, 3	1, –
250....	5335.06	5335.05	*Co*	1	0	3	...
450....	5336.94	5336.97	*Ti*	4	5	1	L10
300....	5337.94	5337.92	*Cr*	([2]) 1	2d	...	1
250....	5339.58	5339.61	*Co*	00	0	2	...
250....	5340.16	5340.12	*Fe*	6	2	10	2
450....	5341.28	5341.23	*Fe-Mn-Co*	([2]) 8	3d	10-15-5	2-8-
250....	5341.68	5341.67	*Ti*	000	0	1	1
300....	5342.87	5342.89	*Co*	1	2	10	...
300....	5343.64	5343.60	*Co-Fe*	2	2	8-1	...
250....	5344.76	5344.77	*V-Co*	000N	0	1-2	1–
350....	5345.96	5345.99	*Cr*	5	2	20	5
250....	5346.77	5346.73	*Fe*	0	1	...	...
250....	5347.65	5347.71	*Co*	00	0	3	...
350....	5348.52	5348.52	*Cr*	4	1	10	3
400....	5349.64	5349.65	*Ca*	4	2	20	5
350....	5349.88	5349.93	*Fe*	1	1	...	...
300....	5350.34	5350.30	*Zr-Mn*	([3]) 1	1	2-3	1-1
300....	5351.18	5351.26	*Ti*	00	0	3	3
250....	5352.18	5352.23	*Co*	1	2N	10	...
500....	5353.60	5353.60	*Fe, Co, Ce, V*	([2]) 3	5d	3, 10, 8, 3	1, –, 10, 5
250....	5355.95	5355.92	*Sc*	00	...	2	...
250....	5357.40	5357.38	*Sc*	00	0	1	...
250....	5359.40	5359.39	*Co*	00	0	10	...
350....	5361.76	5361.81	*Fe-Eu*	1	1	1-3	...
500....	5363.05	5363.06	–	3	8	...	...
250....	5364.66	5364.62	–	000	0	...	...
300....	5365.04	5365.07	*Fe*	5	3	20	2
300....	5365.53	5365.60	*Fe*	3	3	3	1
300....	5366.79	5366.83	*Ti*	000	0d?	1	1
350....	5367.64	5367.67	*Fe*	6	3	20	2
250....	5368.41	5368.40	–	([2]) 0	0d	...	...
300....	5369.81	5369.78	*Co-Ti*	1	1	10-2	–2
350....	5370.16	5370.17	*Fe*	6	3	20	3
500....	5371.69	5371.69	*Fe*	([2]) 7	8	15	6
250....	5372.73	....	...	...	0	...	...
300....	5373.82	5373.90	*Fe, Cr*	2	1d?	2, 1	–, 1
300....	5377.80	5377.80	*Mn*	2N	2	10	3
300....	5379.70	5379.78	*Fe*	3	2	2	1
250....	5380.54	5380.52	–	0N	0	...	...
400....	5381.23	5381.22	*Ti-La*	2	4	–3	L4-1
250....	5382.26	....	...	...	0N	...	...
400....	5383.50	5383.58	*Fe*	3	3	50	6
250....	5385.75	5385.78	–	00	0	...	...
250....	5388.55	5388.55	*Ni, V*	00	0	2, 3	–, 2
350....	5389.67	5389.68	*Fe*	3	2	8	1

TABLE I—*Continued*

Height of Chromosphere	Wave-Lengths		Substance	Intensities			
	Chromosphere	Rowland		Rowland	Chromosphere	Arc	Spark
km							
250....	5390.03	5390.05	–	00	0	...	...
300....	5390.50	5390.55	*Ti, Co, Cr*	(3) 1	1d	2, 2, 1	2, –, 1
350....	5391.61	5391.66	*Fe*	2	2	3	1
350....	5391.84	5391.82	*Fe*	1	1	3	1
250....	5392.18	5392.21	*Sc*	00	0	3	...
400....	5393.39	5393.38	*Fe*	5	3	10	2
350....	5393.65	(5393.62)	*Ce*	...	2	5	3
350....	5394.86	5394.88	*Mn*	2	2d	8	1
250....	5395.37	5395.42	*Fe*	0	0	1	...
250....	5396.47	5396.45	*Ti*	00	0	...	1
800....	5397.34	5397.34	*Fe-Ti*	7d?	6	15-2	6-2
300....	5397.85	5397.82	*Fe?*	1	0	...	...
350....	5398.46	5398.49	*Fe*	3	2	3	...
350....	5399.62	5399.68	*Mn*	1d?	1d?	10	2
400....	5400.65	5400.71	*Fe*	3	3	10	1
250....	5401.77	....	...	...	0	...	...
300....	5402.19	(5402.18)	*V-Co*	...	1d	8-4	10–
350....	5402.96	5402.98	*Y*	0	1	4	8
300....	5403.97	5404.03	*Fe*	2	1	50d?	6
450....	5404.31	5404.36	*Fe*	5	6		
300....	5405.58	5405.55	–	1	1	...	...
600....	5406.04	5405.99	*Fe*	6	8	15	6
300....	5407.00	5406.98	–	1	1	...	...
450....	5407.70	5407.64	*Mn*	(2) 1	2d	10	2
300....	5409.36	5409.34	*Fe*	2	1	1	...
350....	5410.01	5410.00	*Cr*	4	2	20	8
400....	5411.09	5411.12	*Fe*	4	4	20	3
300....	5411.44	5411.43	*Ni*	1	1	8	1
250....	5413.43	(5413.43)	*Co*	...	0	3	...
300....	5414.24	5414.28	–	00	1	...	...
400....	5415.43	5415.42	*Fe-V*	5	3	50-10	6-10
250....	5417.25	5417.25	*Fe*	0	0	1	...
250....	5418.35	5418.41	–	(2) 00	0	...	...
400....	5419.00	5418.98	*Ti*	1	4d?	...	L4
250....	5419.49	....	...	...	1d?	...	...
400....	5420.49	5420.56	*Mn-V*	1N	2	10-2	3-2
300....	5421.14	5421.13	*Cr*	00	1	...	1
350....	5424.27	5424.29	*Fe-V*	6	5	100-5	8-5
300....	5424.85	5424.86	*Ni-Ba*	1	2	5-50	1-3
350....	5425.50	5425.46	–	1	4	...	...
250....	5427.44	5427.43	*Mn?*	0000	0	1	...
600....	5429.93	5429.91	*Fe*	6d?	10	20	6
250....	5430.56	5430.57	*Ni*	00	0	1	...
300....	5431.80	5431.75	*Nd*	000	1	4	3
350....	5432.60	....	...	...	1d?	...	...
400....	5433.10	5433.16	*Fe*	2	3	1	...
250....	5433.85	5433.84	–	00N	0	...	...
500....	5434.74	5434.74	*Fe*	5	5	15	5
350....	5435.99	5436.07	*Ni*	2	1	8	1
350....	5436.52	5436.51	*Fe*	1	1	1	...
350....	5436.83	5436.80	*Fe*	1	1	1	...

TABLE I—*Continued*

Height of Chromo-sphere	Wave-Lengths		Substance	Intensities			
	Chromo-sphere	Rowland		Rowland	Chromo-sphere	Arc	Spark
km							
450....	5437.40	5437.41	–	00	0	...	...
250....	5438.48	5438.51	*Y, Ti*	000	0	5, 1	2, 1
250....	5441.52	5441.55	*Fe*	1	0	1	...
250....	5442.78	....	...	...	0	...	...
250....	5444.76	5444.80	*Co*	00	1	15	...
350....	5445.23	5445.26	*Fe*	4	3	20	2
500....	5447.06	5447.06	*Fe-Ti*	(2) 8	7d?	20-1	6-1
300....	5448.60	5448.58	*Fe*	00	1	1	...
300....	5451.27	(5451.25)	*Sr, Nd*	...	0	20, 4	2, 3
300....	5452.26	5452.31	*Ti*	00	0	...	1
250....	5453.38	5453.44	*Ni*	00	0	2	...
250....	5454.18	5454.20	...	00	0	...	...
300....	5454.80	5454.78	*Cr*	00	0	10	...
500....	5455.79	5455.78	*Fe*	(2) 6	8	50	6
350....	5460.70	5460.72	*Ti*	00	0N	1	2
300....	5462.75	5462.70	*Ni*	1	1	5	...
350....	5463.15	5463.17	*Fe*	3	2	8	1
400....	5463.46	5463.49	*Fe*	3	3	10	1
300....	5464.35	5464.39	*Cr-Fe*	(2) 1	1d	–1	L2-1
300....	5466.61	5466.61	*Fe-Y*	3	2	4-10	1-3
250....	5467.17	5467.20	*Fe*	1	1	1	...
250....	5467.64	5467.61	–	000	0	...	...
250....	5468.05	5468.07	*V*–	(2) 00	0	1	1
250....	5468.67	5468.60	*Ce, Er, Y*	000d?	0	4, 4, 4	3, 1, 2
250....	5469.77	....	...	...	1d	...	...
300....	5470.30	5470.30	*Fe*	00	0	...	...
300....	5470.84	5470.84	*Mn*	(2) 1	2	10	2
300....	5471.47	5471.41	*Ti-V*	000	0	2-2	2-3
400....	5472.82	....	...	...	1	...	...
300....	5473.57	5473.59	*Y*	000	0	3	3
450....	5474.09	5474.11	*Fe*	3	2	5	1
400....	5476.47	5476.50	*Fe*	1	2	3	1
500....	5476.96	5476.99	*Fe, Ni*	(2) 8	8	8, 30	1, 10
250....	5477.91	5477.90	*Ti*	00	1	3	4
250....	5478.67	5478.67	*Fe*	0	0	...	...
250....	5480.22	5480.18	–	000	0	...	...
250....	5480.96	5480.95	*Fe-Cr*	(2) 1	2d	2-2	1-1
300....	5481.58	5481.55	*Fe-Mn-Ti*	(2) 2	1d	4-8-2	-1-3
250....	5482.05	5482.08	*Ti*	00	0	1	2
350....	5483.42	5483.43	*Fe, Co*	(2) 2	2d	2, 10	...
250....	5485.26	5485.27	*Nd*	0000	0	3	2
250....	5485.83	(5485.86)	*Nd*	...	1	8	4
300....	5487.34	5487.35	*Fe*	1	1	1	...
300....	5487.74	5487.72	–	00N	0	...	...
350....	5487.98	5487.96	*Fe*	3	3N	6	1
300....	5489.95	5489.98	*Co*–	(2) 0	1	5–	...
250....	5490.31	5490.37	*Ti*	0	0	3	4
350....	5490.92	5490.92	–	0	2	...	...
250....	5492.10	5492.05	*Fe*	00	0d	1	...
250....	5494.65	5494.68	*Fe*	0	0N	1	...
500....	5497.61	5497.62 5497.74	*Cd, Y* *Fe*	0000 5	8	–, 5 8	50, 8 2

TABLE I—*Continued*

Height of Chromosphere	Wave-Lengths: Chromosphere	Wave-Lengths: Rowland	Substance	Intensities: Rowland	Intensities: Chromosphere	Intensities: Arc	Intensities: Spark
km							
250....	5499.75	5499.80	–	00	0	...	...
400....	5501.67	5501.68	*Fe*	5	5	8	2
250....	5502.24	5502.30	*Cr*	00	0	...	1
300....	5503.22	5503.29	*Fe*	1	2	1	...
300....	5503.65	5503.71	*Y*	00N	0	8	2
300....	5504.18	5504.18	*Ti-Ni*	(?) 1	1	3-2	8–
300....	5506.04	5506.10	*Mn*	1	1	8	1
400....	5507.01	5507.00	*Fe*	5	5	8	2
350....	5508.76	5508.73	*Cr–*	(?) 1	2	...	L3
400....	5510.16	5510.19	*Ni-Y*	(?) 2	4	6-8	–4
350....	5510.82	5510.83	–	00	2	...	...
250....	5511.62	5511.64	–	000	0	...	...
300....	5512.47	5512.47	*Fe*	1	1	1	1
350....	5512.72	5512.74	*Ti*	2	2	5	10
350....	5513.20	5513.20	*Ca*	4	1	8	2
350....	5514.49	5514.56	*Ti*	2	2	3	8
350....	5514.77	5514.75	*Ti*	2	2	3	8
250....	5515.87	5515.86	–	00	0	...	...
250....	5516.55	....	...	...	0	...	...
350....	5516.94	5516.99	*Mn*	(?) 1	2	10	2
250....	5517.25	5517.29	*Fe*	0	0	...	...
250....	5517.76	5517.76	–	00	0	...	...
250....	5518.32	5518.31	–	000	0	...	...
250....	5521.14	5521.16	–	00N	0	...	...
300....	5521.46	5521.43	–	(?) 0	1	...	...
300....	5521.84	5521.80	*Y*	00	0	5	3
350....	5522.65	5522.66	*Fe*	2	2	2	1
350....	5525.81	5525.76	*Fe*	2	2N	2	1
600....	5527.10	5527.03	*Sc*	3	10	8	3
250....	5527.80	5527.80	*Y*	000	0	10	3
400....	5528.61	5528.64	*Mg*	8	6d?	10	5
300....	5529.29	5529.25	*Fe–*	(?) 0	0N	...	...
400....	5531.01	5531.00	*Co*	00N	3	10	1
300....	5533.06	5533.01	*Fe–*	(?) 2	1N	1	...
300....	5533.91	....	...	...	0d	...	...
600....	5535.06	5535.06	*Sr*	2	8	20	3
400....	5535.62	5535.68	*Fe, Ba*	2	1	3, 100	2, 30
250....	5536.52	5536.49	–	000	0	...	...
350....	5537.95	5537.97	*Mn*	(?) 0	1	10	1
350....	5538.71	5538.74	*Fe*	1	0	...	...
300....	5539.46	5539.51	*Fe*	0	0	1	...
300....	5540.29	(5540.30)	*Sr*	...	0	20	3
350....	5543.42	5543.41	*Fe, Sr*	2	2	3, 30	1, 1
350....	5544.21	5544.16	*Fe*	2	1	3	1
350....	5544.87	5544.83	*Y*	000	0	4	2
300....	5546.77	5546.73	*Fe*	2	0	2	...
350....	5550.04	5550.02	–	(?) 0	0	...	...
300....	5552.17	5552.17	*Mn*	000	0	3	1
350....	5553.82	5553.80	*Fe*	1	1	1	...
250....	5554.54	....	...	...	0	...	...
400....	5555.13	5555.12	*Fe*	3	3	6	2

TABLE I—*Continued*

Height of Chromo-sphere	Wave-Lengths		Substance	Intensities			
	Chromo-sphere	Rowland		Rowland	Chromo-sphere	Arc	Spark
km							
250....	5555.80	....	...	...	oN	...	...
250....	5556.65	....	...	...	o	...	...
350....	5558.13	5558.17	*Fe–*	(²) 1	2	2	...
250....	5559.00	(5559.00)	*V-Co*	...	od	2-3	3-1
300....	5559.93	5559.87	–	00	o	...	...
300....	5560.38	5560.43	*Fe*	2	1	2	...
250....	5561.42	5561.46	*Nd*	00	o	2	1
250....	5561.87	(5561.88)	*V*	...	o	2	2
350....	5562.96	5562.93	*Fe*	2	2	2	...
500....	5563.80	5563.82	*Fe*	3	3	3	1
250....	5564.68	....	...	...	o	...	...
500....	5565.92	5565.93	*Fe*	3	5	6	1
250....	5566.32	5566.30	–	00	1	...	...
400....	5567.58	5567.62	*Fe*	2	3	2	...
500....	5569.91	5569.85	*Fe*	6	6	10	2
500....	5573.08	5573.11	*Fe*	(²) 7	7d	20	3
500....	5576.29	5576.32	*Fe*	4	4	10	1
300....	5577.25	5577.25	*Eu*	00	o	10	1
500....	5578.90	5578.95	*Ni*	1	4	5	...
600....	5582.24	5582.20	*Ca, Y*	4	1	10, 8	3, 2
250....	5583.17	5583.19	*Ti*	000	o	...	1
400....	5585.28	....	...	...	1N	...	...
750....	5587.04	5586.99	*Fe*	7	5	30	4
300....	5587.80	5587.80	*Fe*	o	1	...	...
400....	5588.07	5588.08	*Ni*	1	2	5	1
750....	5588.95	5588.98	*Ca*	6	4	20	10
300....	5589.59	5589.58	*Ni*	o	o	4	1
400....	5590.31	5590.34	*Ca*	3	1	8	3
400....	5591.06	5591.04	*Co*	000	1	8	1
400....	5592.49	5592.49	*Ni-Co*	1	4	8-2	2–
400....	5593.87	5593.96	*Ni*	o	2	8	1
500....	5594.79	5594.73	*Ca, Fe*	(²) 5	4	20, 3	8, –
300....	5596.40	5596.40	–	000	oN	...	...
250....	5597.70	....	...	...	o	...	...
500....	5598.64	5598.67	*Ca, Fe*	(²) 5	4	20, 5	8, 1
250....	5599.75	....	...	...	1	...	...
400....	5600.20	5600.24	*Ni*	00	1	4	...
400....	5600.45	5600.45	*Fe*	o	2	1	...
500....	5601.52	5601.50	*Ca-Ce*	3	2	10-4	3-1
500....	5603.13	5603.14	*Ca, Fe*	(²) 7	5	10, 10	3, 1
350....	5603.84	....	...	...	1	...	...
250....	5607.87	5607.89	–	00	o	...	...
350....	5610.35	5610.34	*Ce–*	(²) 00	o	3–	1–
250....	5611.81	5611.86	–	000	o	...	...
250....	5614.80	....	...	...	o	...	...
500....	5615.87	5615.88	*Fe*	6	8d	50	4
300....	5617.44	5617.41	*Fe*	(²) o	1	1	...
250....	5618.87	5618.86	*Fe*	1	1	2	...
250....	5619.85	5619.82	–	o	1	...	...
250....	5620.73	5620.72	*Nd-Fe*	o	1N	10-1	8–
250....	5623.20	5623.18	*Ce*	00	1	1	1

TABLE I—*Continued*

Height of Chromo-sphere	Wave-Lengths		Substance	Intensities			
	Chromo-sphere	Rowland		Rowland	Chromo-sphere	Arc	Spark
km							
350....	5624.24	5624.24	*Fe*	1	1	1	...
400....	5624.76	5624.77	*Fe*	4	3	10	1
350....	5625.61	5625.66	*Ni*–	(2) 1	2d?	8	1
250....	5626.90	5626.92	*Er-Ce*	(2) 00	0	3-1	1–
300....	5627.82	5627.86	*V*	00	1	10	10
250....	5628.20	5628.24	–	000	0	...	...
250....	5628.70	5628.71	*Cr, Ni*	(2) 0	0d	3, 2	2, –
250....	5632.07	5632.06	–	(3) 0	0d	...	...
350....	5634.17	5634.17	*Fe*	3	2	3	...
300....	{5635.07	....	...	...	0	...	...
300....	{5635.43	5635.41*	*C*	000	0N	...	...
300....	5636.01	5636.04	*Fe*	1	1	1	...
350....	5637.46	5637.48	*Fe-Ni*	(2) 2	2d	2-3	–1
350....	5638.49	5638.49	*Fe*	3	3	3	...
250....	5639.03	5638.98	*Ni*	00	0	1	...
300....	5639.72	....	...	...	0N	...	...
300....	5640.48	5640.54	*Er*	0	1	3	...
400....	5641.14	5641.21	*Ti-Sc*	1	2	–3	1-1
350....	5641.66	5641.67	*Fe*	2	2	2	...
250....	5643.03	5642.98	*Fe-Ti*	00	0d	...	...
250....	5643.78	....	...	...	0	...	...
300....	5644.31	5644.37	*Ti*	0	3N	3	10
250....	5645.87	5645.83	*Si?*	1	0	...	...
250....	5646.90	5646.90	–	00	0	...	...
250....	5647.45	5647.46	*Co*	00	0	10	...
250....	5648.86	5648.80	*Ti*	00	1	2	3
350....	5649.66	5649.61	*Cr*	00N	1	2	1
350....	5650.08	5650.10	*Fe*	(2) 2	1	2	...
250....	5650.72	....	...	...	1d	...	...
250....	5651.67	5651.69	*Fe-V*	0	0N	–1	–2
250....	5652.58	5652.54	*Fe*	1	0	1	...
350....	5655.62	5655.61	*Fe*	(2) 3	4d	4	...
600....	5658.06	5658.10	*Sc*	2	5	4	2
500....	{5658.50	{5658.56	*Sc*	0	3	2	1
500....	{5658.88	{5658.96	*Fe-Cr*	(3) 6	2	15-1	1–
300....	5660.92	5660.91	–	(3) 1	1N	...	...
300....	5662.38	5662.37	*Ti*	0	0	3	8
400....	{5662.72	5662.74	*Fe*	4	2	10	1
400....	{5663.15	5663.16	*Y-Ti-Fe*	1	3N	10-1-1	15-2-
350....	5664.09	....	...	...	1	...	...
250....	5666.17	....	...	...	0	...	...
350....	5667.42	5667.37	*Sc*	0	2	2	1
300....	5667.70	5667.74	*Fe*	2	1	2	...
400....	5669.23	5669.26	*Sc*	1	3	3	1
250....	5670.04	5670.06	*Ni, Ce*	(2) 1	0d	2, 4	1, 1
350....	5670.99	5671.07	*V*	0	0	10	10
300....	5672.13	5672.05	*Sc*	0	1N	8	1
350....	5675.64	5675.65	*Ti*	2N	1N	3	4
250....	5676.68	....	...	...	0	...	...
350....	5679.25	5679.25	*Fe*	3	3	3	...

* Head of second carbon band.

TABLE I—*Continued*

Height of Chromosphere	Wave-Lengths: Chromosphere	Wave-Lengths: Rowland	Substance	Intensities: Rowland	Intensities: Chromosphere	Intensities: Arc	Intensities: Spark
km							
300....	5682.63	5682.43	*Ni*	2	1d	8	1
		5682.87	*Na*	5		10	...
350....	5684.44	5684.42	*Sc*	1	3N	3	1
300....	5684.70	5684.71	*Si*	3	0	...	...
250....	5685.67	5685.66	–	0od	0	...	...
300....	5686.74	5686.76	*Fe*	3	2	5	...
350....	5688.45	5688.44	*Na*	6	1N	15	...
300....	5689.59	....	...	...	0d	...	...
300....	5690.72	5690.65	*Si*	3	0	...	...
250....	5691.62	5691.71	*Fe*	2	0	2	...
350....	5693.91	5693.86	*Fe*	3	2	2	...
350....	5695.11	5695.12	*Ni-Cr*	(2) 2	3d	10-3	1-1
350....	5698.55	5698.56	*Cr*	1	3	4	2
350....	5698.80	5698.75	*V*	1	1	10	15
300....	5700.45	5700.45	*Sc-Ni-Cu*	(2) 0	0	5-2-30	1-1-8
400....	5701.34	5701.32	*Si*	1N	0	...	...
500....	5701.70	5701.77	*Fe*	4	2	4	...
400....	5703.78	5703.80	*V*	1	2N	10	10
250....	5705.62	5705.69	*Fe*	1	0	2	...
350....	5706.20	5706.22	*Fe*	3	2	4	...
350....	5707.20	5707.24	*V-Fe*	(2) 1	1	8-1	10–
400....	5708.46	5708.32	*Fe*	1	1d	1	...
		5708.62	*Si*	3N		1	...
400....	5709.64	5709.69	*Fe, Ni*	(2) 10	3	10, 10	1, 2
400....	5711.15	....	...	...	1	...	...
400....	5712.10	5712.10	*Ni-Fe-Ti*	3	3	5-1-1	1–2
400....	5715.33	5715.31	*Ni-Fe-Ti*	5	2	10-2-2	1–2
400....	5718.08	5718.06	*Fe*	4	2	3	...
300....	5719.80	5719.80	–	1	0	...	...
350....	5720.66	5720.67	*Ti*	0	0	1	1
350....	5727.27	5727.27	*V-Ti*	2N	2	10-1	10–
300....	5731.92	5731.98	*Fe*	4	1	3	...
250....	5732.54	5732.52	–	0	0	...	...
250....	5747.96	5747.89	–	1	0	...	...
250....	5748.34	5748.38	*Fe, Ni*	(2) 4	1d	1, 3	...
250....	5752.20	5752.25	*Fe*	4	1	2	...
400....	5753.35	5753.34	*Fe*	5	2	5	1
400....	5754.85	5754.88	*Ni*	5	2	8	1
300....	5760.88	5760.89	*Ni-Fe*	(2) 3	1d	8–	1–
300....	5763.09	5763.12	*Fe-*	(3) 7	1	10–	1–
300....	5774.23	5774.25	*Ti*	0	0	3	3
250....	5778.63	5778.68	*Fe*	1	0	...	...
350....	5780.86	5780.82	*Fe*	2	1	1	...
400....	5782.37	5782.35	*Fe, Cu*	(2) 6	2	5, 50	1, 10
300....	5784.11	5784.08	*Cr*	3	0	8	1
250....	5784.88	5784.88	*Fe*	1	0	...	...
350....	5785.28	5785.19	*Cr*	2	1	6	3
		5785.50	*Fe*	3		...	...
300....	5786.11	5786.04	*Cr-Ti*	(2) 2	0	5-3	1-3
350....	5791.27	5791.24	*Cr-Fe*	3	1	15-1	3–
350....	5798.05	5798.08	–	3	0	...	...

TABLE I—*Continued*

Height of Chromo-sphere	Wave-Lengths		Substance	Intensities			
	Chromo-sphere	Rowland		Rowland	Chromo-sphere	Arc	Spark
km							
300....	5804.54	5804.48	*Ti*	0	0	3	3
300....	5805.48	5805.44	*Ni*	4	0	15	...
300....	5806.91	5806.95	*Fe*	5	0	2	...
250....	5809.48	5809.44	*Fe*	4	0	1	...
300....	5812.14	5812.14	*Fe*	0	0	...	...
300....	5814.21	5814.23	–	00	0	...	...
300....	5816.57	5816.60	*Fe*	5	0	5	...
250....	5828.07	5828.10	–	0	0	...	...
300....	5852.45	5852.44	*Fe*	3	0	...	...
400....	5853.90	5853.90	*Ba*	5	4	200	100
400....	5857.72	5857.67	*Ca*	8	3	10	4
300....	5859.75	5859.81	*Fe*	5	1	4	1
350....	5862.64	5862.64	*Fe*	6	2	10	1
250....	5864.50	5864.46	–	0	0	...	...
250....	5866.38	....	...	...	0	...	...
300....	5867.87	....	...	...	0	...	...
7500....	5876.42	(5875.87)	*He*	...	40	...	...
300....	5879.94	5879.94	*Zr*	1	0	4	1
1000....	5890.4	5890.19	*Na*	30	10	1000	10
400....	5892.7	5892.6	–	3	1	...	...
400....	5893.3	5893.1	*Ni*	4	1	10	1
1000....	5896.1	5896.16	*Na*	20	10	1000	8
300....	5899.5	5899.5	*Ti*	1	0	2	10
300....	5906.0	5905 9	*Fe*	4	0	3	...
400....	5914.2	5914 3	*Fe*	4	2	10	1
400....	5916.4	5916.5	*Fe*	3	1	1	...
300....	5922.0	....	...	...	0	...	...
250....	5928.0	5928.0	*Fe*	2	0	1	...
400....	5929.9	5930.3	*Fe*	(²) 8	2d?	10	1
400....	5935.1	5934.9	*Fe*	5	2	3	1
400....	5948.4	5948.8	*Si*	6	1	...	...
500....	5953.2	5953.0	*Ti-Fe*	(²) 5	2	3-2	10-1
400....	5956.7	5956.9	*Fe*	4	1	1	...
400....	5966.1	5966.1	*Ti*	2	1	2	10
300....	5975.5	5975.6	*Fe*	3	0	2	...
300....	5977.0	5977.0	*Fe*	4	0	3	...
300....	5984.0	5983.9	*Fe*	5	1	4	1
400....	5984.9	5985.0	*Fe*	6	1	8	1
400....	5987.2	5987.3	*Fe*	5	1	4	...
300....	5991.5	5991.6	–	2	1	...	...
300....	5997.6	(5997.4)	*Ba*	...	0	50	10
400....	6002.9	6003.2	*Fe*	6	1	4	1
400....	6008.1	6008.2	*Fe*	4	1	2	...
400....	6016.9	6016.9	*Mn*	6	1	30	1
400....	6020.3	6020.3	*Fe-*	(²) 6	2	10-	1-
400....	6022.0	6022.0	*Mn*	6	1	30	1
400....	6024.1	6024.3	*Fe*	7	2	15	3
300....	6027.2	6027.3	*Fe*	4	1	3	...
300....	6042.3	6042.3	*Fe*	3	1	3	...
400....	6056.3	6056.2	*Fe*	5	1	5	1

TABLE I—*Continued*

Height of Chromo-sphere	Wave-Lengths		Substance	Intensities			
	Chromo-sphere	Rowland		Rowland	Chromo-sphere	Arc	Spark
km							
400....	6065.7	6065.7	*Fe*	7	2	10	1
400....	6079.1	6078.9	*Fe*	(?) 7	2	5	...
300....	6102.1	6102.4	*Fe*	6	1	5	1
300....	6102.8	6102.9	*Ca*	9	1	3	...
300....	6103.6	6103.5	*Fe*–	(?) 5	1	3	...
300....	6116.4	6116.4	*Ni-Fe*	(?) 5	0	20-1	1–
400....	6137.0	6136.9	*Fe*	(?) 11	1	10	3
400....	6138.0	6137.9	*Fe*	7	1	...	...
500....	6141.9	6141.9	*Ba-Fe*	7	5	1000-3	200–
300....	6155.4	6155.4	–	7	0	...	...
300....	6163.8	6163.7	*Ni-Fe*	3	0	10-1	1–
300....	6191.6	6191.6	*Ni, Fe*	(?) 15	1	8, 10	1, 3

Altogether 2841 lines are here tabulated in the spectrum of the chromosphere. In addition to the above, many faint lines were measured. In some parts of the spectrum on account of the great density of the continuous spectrum, it was excessively difficult to set on these faint lines. No lines, even faint ones, were included in the 2841 enumerated, unless they were measured in two or more separate measurements. Even many lines measured at least twice were not included, for it seemed unwise to increase the length of the tables by including lines which could not be more or less positively identified by comparison with Rowland. In attempting to measure the faintest lines, it was at once realized that it was easy to draw on one's imagination and fancy that a line existed where there was possibly nothing more than an accidental lining-up of silver grains in spite of the fact that a rather low power of about 5 was employed in the measurement. It is thought by the writer that very few lines are included in the 2841 which have not a real existence in the chromospheric spectrum. In Table III will be seen that only 126 lines are included which have not been identified with lines in Rowland.

In order to give an idea of the intensities of the lines of the chromosphere, Table II is added which gives the individual intensities of the lines for each hundred angstroms of wave-length.

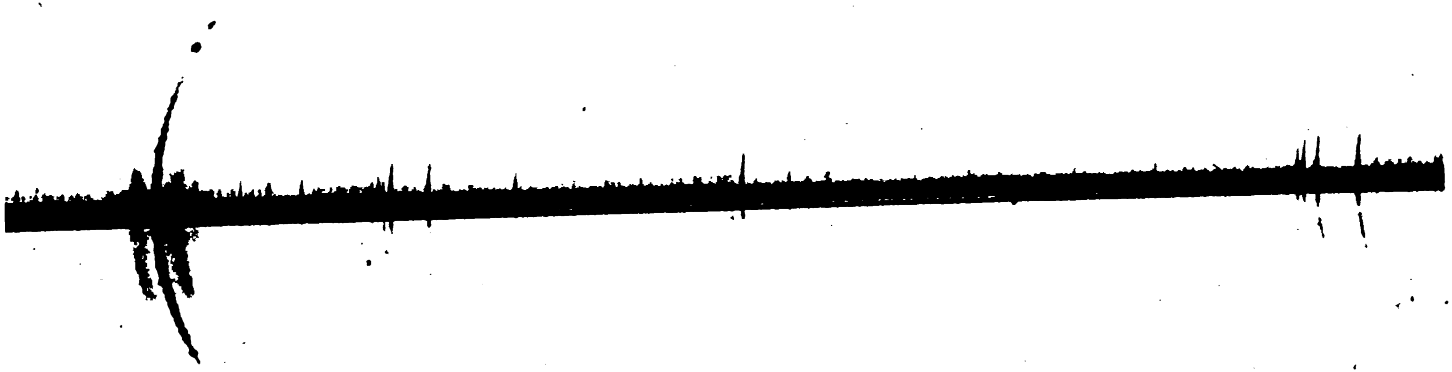
TABLE II

FLASH SPECTRUM INTENSITIES

Arranged according to Intensities

Region	0	1	2	3	4	5	6	7	8	9	10	12	15	20	25	30	35	40	45	50	55	60	70	80	100	Total
3318–3400	22	11	13	7	3	5	1	...	3	...	1	1	...	...	...	...	...	...	...	...	...	...	...	...	...	67
3400–3500	46	22	14	8	7	3	...	1	1	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	102
3500–3600	49	35	15	10	5	5	1	...	1	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	121
3600–3700	32	36	16	6	8	4	5	...	4	...	2	2	1	1	...	...	...	1	...	...	...	...	...	...	...	118
3700–3800	24	33	23	4	8	1	...	...	4	...	4	...	1	1	2	1	1	2	2	2	...	...	...	...	...	113
3800–3900	10	64	41	16	5	4	...	...	3	...	3	...	2	2	...	1	...	1	...	...	1	1	...	...	...	148
3900–4000	19	43	28	8	7	2	5	...	4	...	2	...	1	2	...	...	...	...	...	...	...	1	...	1	1	124
4000–4100	48	43	37	13	6	2	3	...	2	1	1	2	2	1	...	...	...	1	...	...	...	...	...	...	...	162
4100–4200	28	33	40	23	3	10	2	...	3	...	3	1	...	...	...	...	...	...	...	...	...	...	1	...	...	147
4200–4300	21	51	34	21	5	3	2	...	2	...	1	...	4	2	1	1	...	1	...	...	...	...	...	...	...	140
4300–4400	35	27	24	10	6	6	2	...	1	...	3	4	6	...	1	...	...	...	...	...	...	...	...	1	...	120
4400–4500	42	31	33	18	11	3	6	1	2	...	3	1	2	2	...	...	...	1	...	...	...	...	...	...	...	156
4500–4600	35	42	22	13	4	2	2	...	3	...	...	1	3	4	...	...	...	...	...	...	...	...	...	...	...	131
4600–4700	44	34	26	14	4	1	...	...	...	...	...	1	...	...	...	...	...	...	...	...	...	...	...	...	...	124
4700–4800	36	38	21	10	4	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	109
4800–4900	22	37	12	5	...	4	2	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	1	83
4900–5000	43	32	12	3	1	...	...	...	1	...	1	1	...	1	...	...	...	...	...	...	...	...	...	...	...	95
5000–5100	53	29	21	4	...	1	...	...	...	...	...	...	1	...	...	...	...	...	...	...	...	...	...	...	...	109
5100–5200	50	36	20	9	3	...	...	...	...	...	...	1	1	1	1	...	...	...	...	...	...	...	...	...	...	122
5200–5300	45	25	16	4	1	2	2	...	1	...	...	1	...	...	...	...	...	...	...	...	...	...	...	...	...	97
5300–5400	36	17	17	8	2	2	2	...	3	...	...	1	...	...	...	...	...	...	...	...	...	...	...	...	...	88
5400–5500	32	28	11	6	3	2	1	1	4	...	...	1	...	...	...	...	...	...	...	...	...	...	...	...	...	89
5500–5600	34	18	14	4	7	4	2	1	1	...	1	...	...	...	...	...	...	...	...	...	...	...	...	...	...	86
5600–5700	29	24	11	10	1	2	...	...	1	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	78
5700–5800	13	11	9	2	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	35
5800–5900	14	3	1	1	1	...	...	...	...	...	2	...	...	...	...	...	...	1	...	...	...	...	...	...	...	23
5900–6191	9	21	8	...	...	1	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	30
Totals	871	824	539	231	105	69	38	4	44	1	27	18	24	17	5	3	1	8	2	2	1	2	1	2	2	2841

PLATE XVII



SPECTRUM OF CHROMOSPHERE—REGION FROM $H\beta$ TO b GROUP
Negative enlarged sixfold

In Table III is given a summary of all lines arranged according to the element producing them. In making this table, it was a problem to know the best way to treat lines which are due to more than one substance. Although slightly erroneous values may be thereby obtained, it was thought advisable to assign each line to only one element. In all cases, therefore, the element printed first in the column "Substance" in Table I was practically regarded as the sole cause of a line under consideration. A result of this procedure is seen with the element hydrogen. Thirty-five lines of hydrogen appear in Table I, the line at 4686.00, and 34 of the well known series. But 30 appear in Table III, for the reason that some of the fainter lines of the series have a combined source, and have been assigned to other sources than *H* as *Fe* or *Ti*.

In the first column under "Element," — means that the lines were identified with lines in Rowland's tables, but no source could be assigned to the lines. "Unidentified" means that the lines could not be identified with a line in Rowland. It will be seen that there are but 126 of these, or in other words it has been found possible to assign sources to all but 4 per cent of the lines measured in the chromosphere.

An interesting comparison is made by tabulating the totals for the various elements given in the last column in Table III according to their atomic weights. In Table IV is given the periodic table of atomic weights with the international values adopted in 1910. This table is taken from the values in *Encyclopaedia Britannica*, 11th edition, Vol. 9, p. 258, under "Element." In the table, under each element is given, first the atomic weight, and second (*in italics*) the total number of lines from each element found in the chromospheric spectrum. A heavy line is drawn to include all the elements found. In addition to the elements within this heavy line there is also hydrogen, represented by 30 lines. *Ag* (atomic weight, 108) and *Cd* (atomic weight, 112) seem to be represented in the chromosphere by weak lines in combination with stronger lines of other elements, and possibly also *Nb* (atomic weight, 93) and *Mo* (atomic weight, 96).

There are thus found in the chromosphere nearly all the elements which are found in the ordinary solar spectrum. In the

TABLE III

FLASH SPECTRUM INTENSITIES

Arranged according to Elements

Element	3318 to 3400	3400 to 3500	3500 to 3600	3600 to 3700	3700 to 3800	3800 to 3900	3900 to 4000	4000 to 4100	4100 to 4200	4200 to 4300	4300 to 4400	4400 to 4500	4500 to 4600	4600 to 4700	4700 to 4800	4800 to 4900	4900 to 5000	5000 to 5100	5100 to 5200	5200 to 5300	5300 to 5400	5400 to 5500	5500 to 5600	5600 to 5700	5700 to 5800	5800 to 5900	5900 to 6191	Total
Fe	6	21	37	36	35	37	29	32	36	40	18	22	22	22	20	18	34	31	33	33	33	36	28	23	15	7	25	729
Ti	22	12	11	12	11	4	13	18	12	15	23	28	21	19	12	11	13	25	11	9	8	7	5	5	2	2	2	333
Cr	14	10	3	7	3	1	6	3	6	15	11	5	13	28	9	9	3	2	7	13	10	4	2	3	4	...	...	191
V	2	3	12	2	7	6	12	21	13	13	10	20	10	5	6	5	2	2	3	4	2	2	2	3	3	...	...	170
C	...	...	4	1	22	65	...	...	12	1	...	...	...	3	3	...	3	13	31	...	...	...	...	1	...	1	...	160
Ni	4	8	11	5	3	3	2	2	1	...	2	5	4	4	11	10	14	15	10	4	1	6	6	6	4	2	3	146
Zr	8	17	8	13	6	6	7	9	7	16	7	8	4	4	3	1	...	...	...	1	1	...	...	...	...	1	...	127
Co	3	10	15	3	4	7	9	9	7	...	...	2	6	...	3	3	1	...	...	5	9	3	2	1	...	...	...	102
Mn	...	6	6	...	1	4	2	14	2	7	...	8	2	...	8	2	...	1	1	1	3	4	4	...	...	...	2	78
Ce	...	1	1	...	...	...	7	9	15	6	5	10	5	1	...	...	...	1	...	1	2	1	...	2	...	...	...	67
Sc	4	...	7	6	...	...	3	7	1	1	5	2	...	1	3	...	...	2	...	1	4	...	1	6	1	...	...	55
Nd	...	...	...	...	1	...	5	6	6	6	5	4	3	1	3	3	1	1	1	2	1	3	1	1	...	...	...	54
Y	1	1	1	6	4	1	3	2	2	2	4	3	...	1	1	2	2	2	2	...	...	3	4	1	...	...	...	48
La	2	...	...	...	3	1	5	4	4	8	2	2	3	1	2	1	2	...	2	1	...	...	...	...	...	...	...	43
Ca	...	...	...	1	1	...	3	1	...	3	3	4	4	...	...	...	...	1	...	3	1	...	6	2	...	1	1	35
H	...	...	...	16	7	2	1	...	1	...	1	...	...	1	...	1	...	...	...	...	...	...	...	...	...	...	...	30
Gd	...	1	2	...	...	1	1	8	1	1	4	2	1	...	...	...	...	...	...	...	...	...	...	...	...	...	...	22
Sa	...	...	...	1	...	...	...	...	...	2	...	6	6	3	1	...	...	...	...	...	...	...	...	...	...	...	...	19
Er	...	2	...	3	1	2	...	1	3	1	1	...	...	...	...	...	1	...	...	...	...	...	...	2	...	...	...	17
He	...	...	...	1	1	1	1	2	3	...	1	2	...	...	1	...	1	1	...	...	...	...	...	...	...	...	...	15
Sr	...	1	...	...	...	...	...	1	...	1	1	1	...	1	1	...	...	...	...	2	...	1	2	...	...	...	...	12
Ba	...	...	...	...	...	1	1	...	2	...	...	1	2	...	...	...	1	...	...	...	...	...	...	...	...	1	2	11
Mg	...	...	...	...	...	3	...	...	...	...	...	1	1	...	1	...	...	...	3	...	...	...	1	...	...	...	...	10
Si	...	...	...	...	...	...	1	...	1	...	...	...	...	...	...	...	...	...	...	...	...	...	...	3	1	...	1	7
Eu	...	...	...	...	...	...	1	...	1	...	1	...	...	1	...	...	1	...	...	...	...	...	1	...	...	...	...	6
Zn	...	...	...	...	...	...	...	...	...	...	...	...	...	1	1	1	1	...	...	...	...	...	...	...	...	...	...	4
Al	...	...	1	...	...	...	2	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	3
Na	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	1	...	2	...	3
Dy	...	...	...	...	...	...	1	...	...	1	...	1	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	3
Cu	...	...	...	...	...	...	...	1	...	...	1	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	2
Pr	...	...	...	...	...	...	...	...	...	...	...	1	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	1
Nh	...	...	...	...	...	...	...	...	1	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	1
—	1	3	...	1	3	3	5	10	9	9	16	11	12	20	15	6	10	7	10	6	10	14	12	8	4	4	2	211
Unidentified	...	6	2	4	...	...	4	2	1	1	5	7	12	7	5	10	5	5	8	11	3	5	9	10	1	2	1	126
Totals	67	102	121	118	113	148	124	162	147	149	126	156	131	124	109	83	95	109	122	97	88	89	86	78	35	23	39	2841

TABLE IV

Periodic Table of Atomic Weights

In italic figures are given the total number of lines for each element found in the chromosphere.

He 4 *15*	*Li* 7 ..	*Be* 9 ..	*B* 11 ..	*C* 12 *160*											*N* 14 ..	*O* 16 ..	*Fl* 19 ..
Ne 20 ..	*Na* 23 *3*	*Mg* 24 *10*	*Al* 27 *3*	*Si* 28 *7*											*P* 31 ..	*S* 32 ..	*Cl* 35 ..
A 40 ..	*K* 39 ..	*Ca* 40 *35*	*Sc* 44 *55*	*Ti* 48 *333*	*V* 51 *170*	*Cr* 52 *191*	*Mn* 55 *78*	*Fe* 56 *729*	*Ni* 59 *146*	*Co* 59 *102*	*Cu* 64 *2*	*Zn* 65 *4*	*Ga* 70 ..	*Ge* 72 ..	*As* 75 ..	*Se* 79 ..	*Br* 80 ..
Kr 83 ..	*Rb* 85 ..	*Sr* 87 *12*	*Y* 89 *48*	*Zr* 91 *127*	*Nb* 94 ..	*Mo* 96 ..		*Ru* 102 ..	*Rh* 103 ..	*Pd* 106 ..	*Ag* 108 ..	*Cd* 112 ..	*In* 115 ..	*Sn* 119 ..	*Sb* 120 ..	*Te* 127 ..	*I* 127 ..
Xe 131 ..	*Cs* 133 ..	*Ba* 137 *11*	*La* 139 *43*	*Ce* 140 *67*	*Pr* 141 *1*	*Nd* 144 *54*	*Sa* 150 *19*	*Eu* 152 *6*	*Gd* 157 *22*								
			Tb 159 ..	*Dy* 162 *3*	*Nh* ? *1*	*Er* 167 *17*	*Tm* 168 ..	*Ny* 172 ..	*Lu* 174 ..								
					Ta 181 ..	*W* 184 ..		*Os* 191 ..	*Ir* 193 ..	*Pt* 195 ..	*Au* 197 ..	*Hg* 200 ..	*Tl* 204 ..	*Pb* 207 ..	*Bi* 208 ..		
		Ra 226 ..		*Th* 232 ..		*U* 238 ..											

chromosphere in addition is found helium, and also a few of the rare earths like *Dy* and *Nh* which have been isolated since Rowland's identifications were made.

According to the comparisons of Rowland (Young, *General Astronomy*, p. 215), the elements in the solar spectrum arranged in the order of the total number of lines identified are as follows for the first twenty-five elements: $\overset{1}{Fe}$, $\overset{2}{Ni}$, $\overset{3}{Ti}$, $\overset{4}{Mn}$, $\overset{5}{Cr}$, $\overset{6}{Co}$, $\overset{7}{C}$, $\overset{8}{V}$, $\overset{9}{Zr}$, $\overset{10}{Ce}$, $\overset{11}{Ca}$, $\overset{12}{Sc}$, $\overset{13}{Nd}$, $\overset{14}{La}$, $\overset{15}{Y}$, $\overset{16}{Nb}$, $\overset{17}{Mo}$, $\overset{18}{Pd}$, $\overset{19}{Mg}$, $\overset{20}{Na}$, $\overset{21}{Si}$, $\overset{22}{H}$, $\overset{23}{Sr}$, $\overset{24}{Ba}$, $\overset{25}{Al}$. In the chromosphere, according to Table III, the order is: $\overset{1}{Fe}$, $\overset{2}{Ti}$, $\overset{3}{Cr}$, $\overset{4}{V}$, $\overset{5}{C}$, $\overset{6}{Ni}$, $\overset{7}{Zr}$, $\overset{8}{Co}$, $\overset{9}{Mn}$, $\overset{10}{Ce}$, $\overset{11}{Sc}$, $\overset{12}{Nd}$, $\overset{13}{Y}$, $\overset{14}{La}$, $\overset{15}{Ca}$, $\overset{16}{H}$, $\overset{17}{Gd}$, $\overset{18}{Sa}$, $\overset{19}{Er}$, $\overset{20}{He}$, $\overset{21}{Sr}$, $\overset{22}{Ba}$, $\overset{23}{Mg}$, $\overset{24}{Si}$, $\overset{25}{Eu}$.

By comparing the relative orders of the elements in the two lists just given for sun and chromosphere, and also having regard to the general intensities of the lines in the various elements, we find that the elements can be divided into three groups as follows:

GROUP I.—*Lines strong in the sun, strong in the chromosphere: Ca, Mg, Al.*

Although there are relatively more lines in the solar spectrum for each element than in the chromosphere, these are grouped together on account of the great strength of H and K, the *b* group, etc.

GROUP II.—*Lines relatively stronger in the chromospheric than in the solar spectrum:*

H, He, Ti, Cr, C, V, Zr, Sc, La, Y, Sr, Ba, Nd.

GROUP III.—*Lines relatively stronger in the solar than in the chromospheric spectrum:*

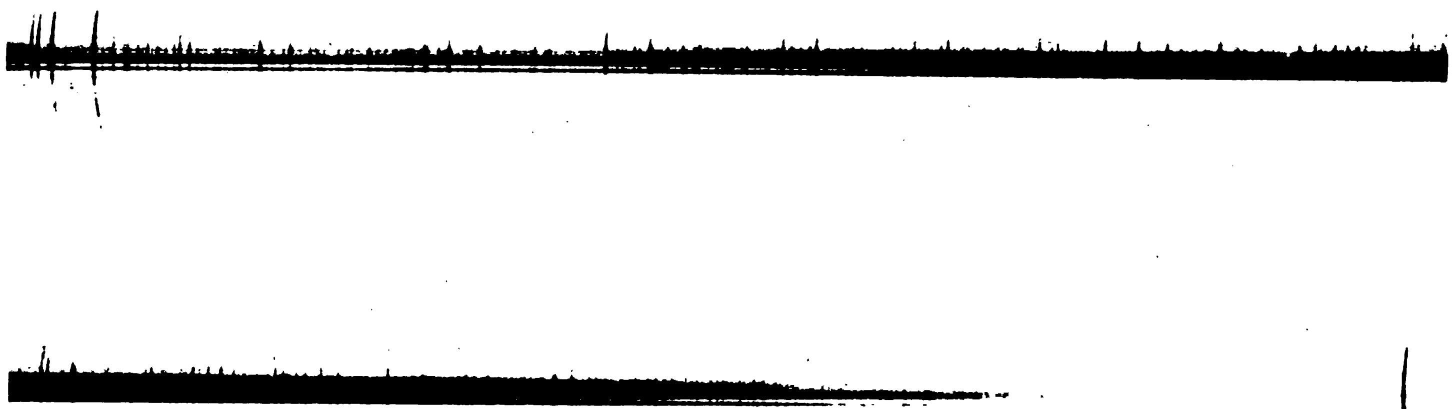
Fe, Ni, Co, Mn, Na, Nb, Mo, Pd.

Although *Fe* heads the list in sun and chromosphere, it is put in this group along with *Ni* and *Co*.

This is practically the same grouping as was obtained in the discussion of the 1901 eclipse.[1] From the 1901 eclipse, the grouping came as a result of comparing *intensities* only. The grouping as above, coming from comparing *numbers* only must give the same results as a comparison of intensities, for the reason that if all the

[1] *Publications of the Naval Observatory*, Second Series, Vol. 4, App. 1, p. 290; *Astrophysical Journal*, 15, 97, 1902.

PLATE XVIII



Spectrum of Chromosphere—Region from *b* Group to D_3
Negatives enlarged sixfold

lines of a given element are relatively strengthened, more than the average number of the fainter lines necessarily become visible in the chromosphere, and, consequently, more lines are measured.

It is thus seen that *Fe* and *Ti*, for instance, belong to different groups. This means that on the average a *Ti*-line of any given intensity in the sun, say 5, would have a stronger line in the chromosphere corresponding to it than a *Fe*-line of the same intensity.

ENHANCED LINES

As mentioned above, the chromospheric and solar spectra agree exactly as to wave-lengths, but differ very greatly in their intensities. The differences in intensity are accentuated in the case of the "enhanced" lines, which are those more intense in the spark than they are in the arc. The importance of enhanced lines in eclipse spectra was first recognized by Sir Norman Lockyer. The present measures confirm this important rôle played by the enhanced lines, and, consequently, there is included in the spark intensities Lockyer's list of enhanced lines, denoted by prefixing the letter "L." By referring to the intensities in arc and spark, one can see for himself which lines, in addition to the L-lines, are enhanced.

Reference to Table I will show that the enhanced lines in the chromosphere are not only stronger but they extend to higher levels than do the unenhanced lines. These greater heights bring as a natural result several important consequences: (1) changes in thermal conditions; (2) changes in electrical conditions; (3) changes in pressure; (4) a more ready mixing with the gases of the upper chromosphere, such as hydrogen. A brief glance at the results of the above four changes of condition may not be without interest.

1. Lockyer's explanation of the brilliancy of the enhanced lines has always been one mainly of temperature. According to him, the spark is hotter than the arc, and at the higher temperature of the spark, the elements are dissociated. Applied to the chromosphere, this has always borne a curious consequence. To account for the increased strength of the enhanced lines in the chromosphere on Lockyer's supposition that they are the result of tempera-

ture only, we must assume that, as we ascend to higher levels above the photosphere, we reach greater and greater temperatures, a conclusion which seems to be a rather contradictory one. The majority of spectroscopists disagree with Lockyer. As far back as 1884, Liveing and Dewar[1] stated that "there is no good reason for assuming that the energy which takes the form of radiation in the electric discharge through a gas must first take the form of motion of translation of the particles, on which temperature depends." According to Hartmann,[2] in comparing arc and spark spectra, "spark lines do not correspond to a thermal radiation but rather to electro-luminescence."

The question of temperature in its relation to spectrum lines is summed up by Kayser[3] as follows: "We can prove no connection between the spectrum and the temperature, and all conclusions concerning the appearance of certain lines and bands which are based on temperature conditions are decidedly unsound." For the present purpose, it is not necessary to enter the controversy as to whether the spark is hotter or colder than the arc. It seems certain that Lockyer's conclusion that the higher chromosphere is at a higher temperature than the lower chromosphere is erroneous, but it is equally certain that the vapors of the higher chromosphere are nevertheless at relatively high temperatures. To the present writer it seems that thermal changes play a very unimportant rôle in the explanation of the causes of the enhanced lines.

2. As is well known, variations in electrical conditions change enormously the character of the lines of the spectrum. Unfortunately, we are not familiar with the nature of the electro-luminescence at the surface of the sun, nor are we aware of how the enhanced lines in particular are altered by changes in these conditions, and hence we shall be forced to leave this for the present without further investigation.

3. Much excellent work has been done on the subject of the pressures at the sun's surface. The most recent determination of the pressure in the reversing layer has been made by Fabry and

[1] *Phil. Mag.* (5), **18**, 161, 1884.

[2] *Astrophysical Journal*, **17**, 270, 1903.

[3] *Handbuch der Spectroscopie*, Bd. II, p. 181.

Buisson,[1] who give a value of 5 atmospheres. Perot's value is substantially the same. In the chromosphere at the average heights of the enhanced lines, the pressure would be very much less. According to the researches of Gale and Adams,[2] the titanium arc at reduced pressures shows a marked increase of relative intensity for the enhanced lines. Barnes found a similar result for *Al*, *Mg*, and *Cu*.[3] Moreover, Gale and Adams found that the enhanced lines show materially larger displacements both at the sun's limb and under pressure than do the other lines. They also showed that at moderate pressures the enhanced lines remain bright while a majority of the other lines are reversed. These various considerations prove that pressure is a very potent factor in altering the character of spectrum lines and that enhanced lines in particular are very sensitive to changes in pressure. Conclusions seem obvious. Enhanced lines, for some reason (as seen from Table I), in the chromosphere ascend to much greater heights on the average than do lines of the same element not enhanced. At these higher elevations, pressure is much reduced. This reduction in pressure causes a brightening of these lines. It was pointed out above that since the moon gradually covers up the chromosphere, the strongest lines, in general, are those which correspond to vapors which extend to the greatest heights. But high elevations cause a reduction in pressure which entails a strengthening of the enhanced lines. The prime cause, therefore, of the strengthening of the enhanced lines is the heights to which the vapors ascend. These great heights bring an additional consequence as enumerated in (4), viz., the vapors belonging to the enhanced lines are more readily mixed with the higher gases of the chromosphere such as helium and hydrogen. It is a well known fact[4] that an atmosphere of hydrogen has the effect of strengthening the enhanced lines. Hence, we find here another cause for the greater strength of the enhanced lines.

The final conclusion therefore seems to be that the vapors forming the enhanced lines ascend to relatively high altitudes from

[1] *Astrophysical Journal*, **31**, 97, 1910.

[2] *Ibid.*, **35**, 10, 1912.

[3] *Ibid.*, **34**, 159, 1911.

[4] Crew, *Ibid.*, **12**, 167, 1900.

which results a decrease in pressure and a mixing with hydrogen, and that on account of height, reduced pressure, and the presence of hydrogen, the enhanced lines become relatively strong.

ELEMENTS IDENTIFIED

As may be seen from Tables III and IV, 32 elements are found in the chromosphere. As before stated, these two tables give only those identifications which may be regarded as the principal cause of each chromospheric line. In addition to the lines in Tables III and IV, there are many in each element not enumerated there because they were of minor importance in the blended lines, but which, nevertheless, appear in Table I and correspond to lines of the chromosphere. A comparison of Table I with Vol. 1 of Exner and Haschek's tables where is given a codex of the strongest lines of the different spectra shows that, practically without exception, the chief lines of each of the 32 elements are found in the chromosphere.

From the tables, one can readily see the elements identified. A few need special mention.

Hydrogen.—Including H_α, which is on the plane grating spectrum, but which is not enumerated in Table I, the wave-lengths of 35 lines of the hydrogen series are given. As above stated, on account of the great heights to which hydrogen ascends, it is impossible to determine wave-lengths from slitless spectra with as great an accuracy as if a slit had been used. Nevertheless, the measured wave-lengths agree closely with Balmer's well known law where the limit of the series is at λ 3646.125. At the thirty-fifth line, the hydrogen lines crowd closely together in the spectrum, being separated by approximately 0.5 angstrom. A few additional hydrogen lines were measured, but they are not tabulated. The values of wave-lengths agree closely with those determined by Dyson from the eclipses of 1900, 1901, and 1905.[1]

A line near λ 4686 has been observed in many eclipse spectra. Fowler,[2] by laboratory experiments, has found this to belong to

[1] *Phil. Trans. Roy. Soc.*, **206** A, 438, 1906.

[2] *Monthly Notices, R.A.S.*, **73**, 62, 1912.

the principal series of hydrogen and measured its wave-length as 4685.98 on Rowland's scale. This line is well seen in the present spectra as a diffuse line extending to 2000 km above the photosphere. From these slitless spectra, accurate measures of its wave-length are rather difficult. The value of the wave-length from the present spectra is 4686.00.

If any lines of hydrogen are present other than those belonging to the well known series and this one line of the principal series, the lines must be weak in intensity.

The rare earths.—Of the 2841 lines tabulated, no less than 336, or about one-eighth of the total, belong to the rare earths. Chemists have been able to divide and subdivide these, so that at the present (1913), the separation of these elements is given in Table V.[1] The elements are given in *italics*.

Reference to Exner and Haschek, Bd. I, p. 35, will show that these elements are very rich in lines both in the arc and spark. Practically, all the rare earths are represented in the chromosphere by their strongest lines.

Rare gases of atmospheric air.—In 1903, the writer announced[2] the presence of neon and argon in the flash spectrum of the 1901 eclipse. According to Evershed,[3] these conclusions were based on insufficient evidence, since the wave-lengths of the neon lines were not known at that time with sufficient accuracy to give a decisive result.

The writer has not thought it necessary to here tabulate wave-length comparisons. He finds that in the region λ 3300 to λ 6200, there are twenty-five lines of neon having an intensity of 4 or greater. Of these lines, there are only four falling sufficiently close to chromospheric lines to be considered coincidences, and these lines are not the strongest lines of neon. In the argon spectrum in the same region, there are sixty-one lines with intensities greater than 4 in the red and blue spectra as given by Kayser, and but fourteen cases which might be called coincidences, the lines again not being

[1] See *Encyclopaedia Britannica*, 11th ed., Vol. 22, p. 909, under "Rare Earths."

[2] *Astrophysical Journal*, 17, 224, 1903.

[3] *Kodaikanal Bulletin No. 27*, 1912.

TABLE V

RARE EARTHS

- Ceria
  - *Ceria*
  - Lanthana
    - *Lanthana*
    - Didymia
      - Samaria
        - *Samaria*
        - *Europia*
      - Didymia
        - *Praesodymia*
        - *Neodymia*

- Yttria
  - *Yttria*
  - Erbia (Mosander)
    - Terbia (Delafontaine)
      - *Terbia*
      - *Gadolinia*
  - Terbia (Mosander)
    - Erbia (Berlin)
      - Ytterbia
        - Ytterbia
          - *Neoytterbia*
          - *Lutecia*
        - *Scandia*
      - Thulia
      - Soret's X
        - Holmia
          - Holmia
            - *Neoholmia*
          - *Dysprosia*
      - Erbia

the strongest. In both the neon and argon coincidences, the lines are sufficiently identified with lines in Rowland.

Although Mr. Evershed and the writer do not in all cases agree on the identification of the lines in the violet, they arrive at the same conclusion, viz., that there is no evidence to show that neon, argon, krypton, or xenon are present either in the chromosphere or in the ordinary solar spectrum.

Radioactive substances.—The writer's opinion regarding radium, radium emanation, and uranium in the sun has been published in *Astronomische Nachrichten*, 4600, and *Popular Astronomy*, **21**, 1, 1913. His conclusions, which do not agree with those of Dyson,[1] are as follows (*Popular Astronomy*): "From theoretical considerations we are positively convinced that there must be radium in the sun. But to prove this is another problem! With the spectra we already have, we can prove nothing more than accidental coincidences."

THE FLASH SPECTRUM WITHOUT AN ECLIPSE

Comparisons of the present spectra with those obtained by Hale and Adams[2] will not be without interest. Their photographs were made with the 60-foot tower telescope and 30-foot spectrograph of Mount Wilson. The solar image given by this telescope is 6.7 inches (17 cm) and the dispersion is such that for photographs in the second order 1 mm = 0.9 angstrom.

Although their dispersion was about twelve times that used by the writer, in the region from λ 4492 to λ 4584 they give altogether 37 lines. In the same region in Table I will be found 118 lines, or over three times as many. In the green region, where their visual object-glass performed to much better advantage, they have photographed between λ 5111 and λ 5198. The writer made a close comparison (which those interested may readily do) between their wave-lengths and his values in Table I, and reached the following conclusions: (1) In spite of the twelvefold greater dispersion, the wave-lengths have about an equal accuracy. (2) Practically every line in Hale and Adams is found in Table I. (3) From

[1] *Astronomische Nachrichten*, 4589.

[2] *Astrophysical Journal*, **30**, 222, 1909.

Hale and Adams' list, there are some curious omissions. They have no lines between λ 5126.18 and λ 5130.76, omitting the chromospheric line at λ 5129.41, an enhanced *Ti*-line of intensity 3. They have measured no lines between λ 5138.70 and λ 5141.38 leaving out the *Fe-V* line of intensity 4 in the chromosphere at λ 5139.60. Many relatively strong lines in the chromosphere did not appear in their photographs, although very weak lines of the green carbon band were measured. It seems that the difference in the two spectra, with and without an eclipse, is one mainly of elevation, the spectra without an eclipse being taken at a higher elevation. Consequently, eclipse spectra include all the lines taken without an eclipse, and in addition lines of lower level, the latter probably outnumbering the former. Taking the whole spectrum, it may not be unreasonable to say that the 1905 flash spectrum would have twice as many lines with wave-lengths quite as accurate as those obtained with the 60-foot tower telescope. The results from the use of the 150-foot tower telescope at Mount Wilson will be watched with the greatest interest.

GENERAL CONCLUSIONS

As a result of these 1905 eclipse spectra it seems safe to make the following conclusions:

1. The flash spectrum is a reversal of the Fraunhofer spectrum.

2. The flash is not an instantaneous appearance, but the chromospheric lines appear gradually. At the beginning of totality, those of greatest elevation appear first, and at the end of totality remain the last. The "reversing layer" which contains the majority of the low-level lines of the chromosphere is about 600 km in height.

3. Wave-lengths in chromospheric and solar spectrum are practically identical.

4. The chromospheric spectrum differs greatly from the solar spectrum in the intensities of the lines.

5. These differences in intensity find a ready explanation in the heights to which the vapors ascend.

6. Especially prominent in the chromosphere are the enhanced lines which become brighter mainly because at the heights to which

they ascend the vapors are mixed with hydrogen at reduced pressures.

7. The great value of gratings for eclipse work is shown by the present spectra. The normal spectrum permits a ready determination of wave-lengths which are quite as accurate at the red end of the spectrum as they are at the violet end. Of gratings, plane and concave, the latter are to be preferred.

8. Compared with the writer's eclipse measures of 1901, the present spectra are in better focus, and extend farther to both the red and violet ends. The wave-lengths of the present paper were closely compared with those of Evershed[1] for the eclipses of 1898 and 1900, and with those of Dyson[2] obtained at the eclipses of 1900, 1901, and 1905, both of whom used prisms. Their wave-lengths are quite accurate in the violet, but gradually decrease in accuracy toward the red due to the decrease of dispersion inherent in prismatic spectra.

9. The present spectra were obtained at the central line of totality. It might be well to go in 1914, as Evershed went in 1900, near the edge of the shadow-path. This would permit of relatively longer exposures on the regions of lower-level. If spectra were obtained with a dispersion equal to or greater than the present, comparisons would be very interesting. It would be desirable to extend the spectrum farther into the red by the use of plates sensitive to the red.

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August 1913

[1] *Phil. Trans. Roy. Soc.*, **201** A, 457, 1903

[2] *Ibid.*, **206** A, 438, 1906.

DARK REGIONS IN THE SKY SUGGESTING AN OBSCURATION OF LIGHT

By E. E. BARNARD

The so-called "black holes" in the Milky Way are of very great interest. Some of them are so definite that, possibly, they suggest not vacancies, but rather some kind of obscuring body lying in the Milky Way, or between us and it, which cuts out the light from the stars. This explanation seems to become more and more plausible the more we know of these objects. In previous papers I have called attention to this possible obscuring matter, splendid examples of which are connected with the great nebulosities about the stars ρ *Ophiuchi* and ν *Scorpii*. See *Astrophysical Journal*, 31, 8, 1910, for an article bearing on this subject.

One of the most remarkable of these spots—remarkable because of its smallness and definite form—is in one of the dense star-clouds, in the position:

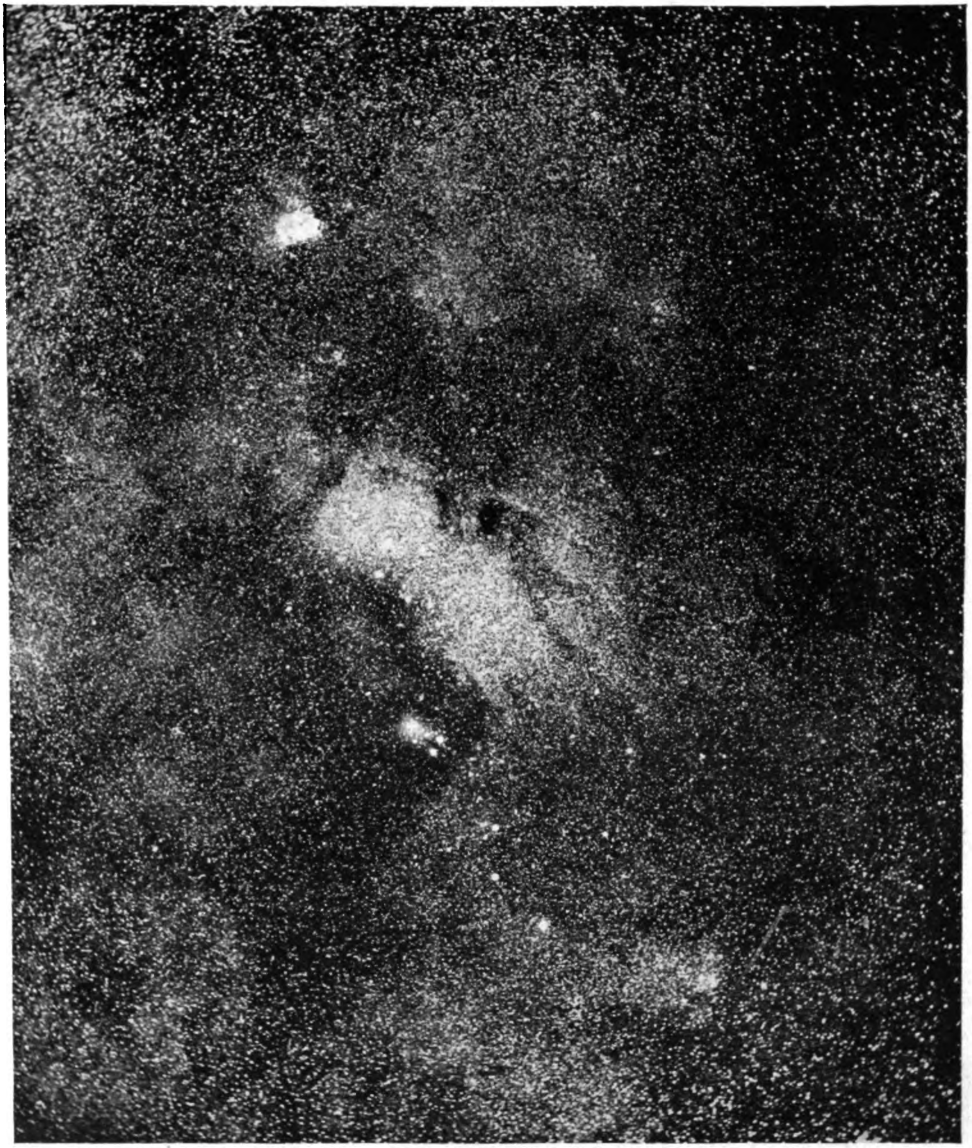
$$1855.0 \qquad \alpha = 18^h 7^m \qquad \delta = -18^\circ 15'.$$

Photographs taken with portrait lenses show it to be about 15′ in diameter, north and south, with its following side very sharply defined. The preceding side is diffused and sprinkled with small stars. Near the center is a considerable star, with one or two smaller ones near it. To show the location of this object in the sky, a photograph taken by the writer at Mount Wilson, California, on July 31, 1905, with the 10-inch Bruce lens of the Yerkes Observatory, with an exposure of $4^h 30^m$ is given (Plate XIX). Its true form, however, is more clearly shown in the fourfold enlargement (Plate XX, Fig. 2).

Known to me in my early days of comet-seeking, this object has always been of the deepest interest, and it was one of the first subjects that I sought to study with the Willard lens at the Lick Observatory. I have also examined it repeatedly with the great telescopes of the Lick and Yerkes observatories. In these visual

PLATE XIX

North



E. E. Barnard

Scale { 1 in. = 77'.9 / 1 cm = 30'.7 }

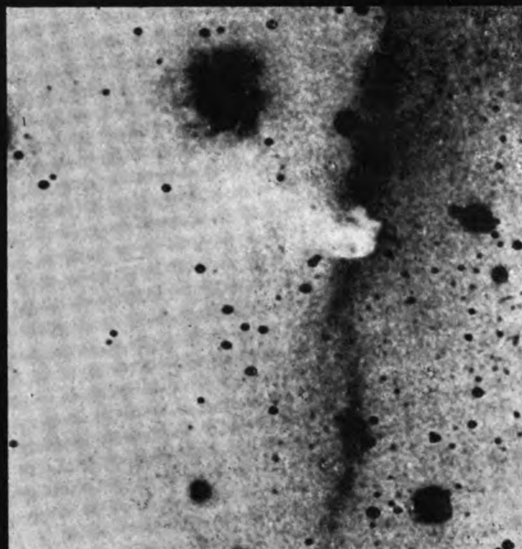
BLACK SPOT IN STAR CLOUD IN SAGITTARIUS

1855.0 $\alpha = 18^h 7^m$ $\delta = -18°15'$

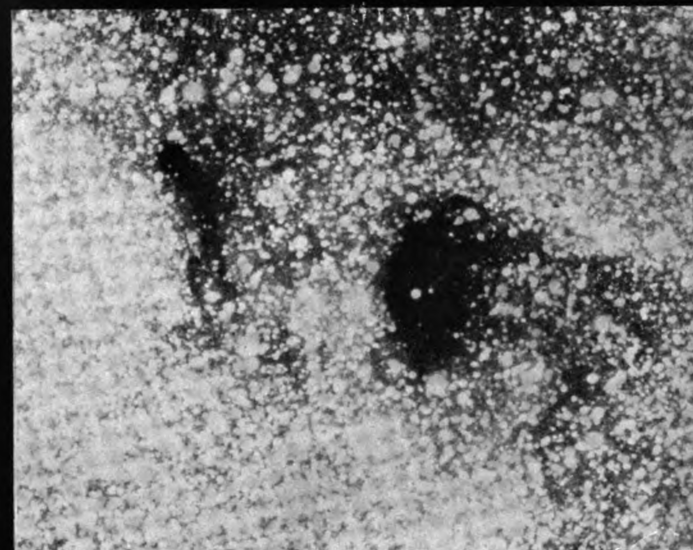
10-inch Bruce telescope 1905 July 31, Exposure $4^h 30^m$

PLATE XX

North



North



E. E. Barnard

FIG. 1 (Negative)

BLACK SPOT IN NEBULOUS STREAM SOUTH FROM ζ ORIONIS

1855.0 $\alpha = 5^h 33^m.6$ $\delta = -2°35'$

Enlarged 4.3 times, Scale $\begin{cases} 1 \text{ in.} = 15'.1 \\ 1 \text{ cm} = 5'.9 \end{cases}$

FIG. 2 (Positive)

BLACK SPOT IN STAR CLOUD IN SAGITTARIUS

1855.0 $\alpha = 18^h 7^m$ $\delta = -18°15'$

Enlarged 4.1 times, Scale $\begin{cases} 1 \text{ in.} = 16'.0 \\ 1 \text{ cm} = 6'.3 \end{cases}$

observations there has sometimes been a suspicion that I could see an actual object at this point. An observation of this kind, however, requires both good definition and good transparency. A little unsteadiness of the air blurs the light of the many near-by stars into a mistiness of the field, and a want of transparency cuts off any feebly luminous object and readily defeats any effort to see it. On the night of July 27 of the present year, the conditions were very favorable, both for transparency and for steadiness. Under these conditions the hole or spot was examined very carefully with the 40-inch telescope. With its following edge cutting across the middle of the field, which is some three times smaller than the spot, it was quite distinctly seen that the preceding half of the field, in which there were no stars, was very feebly luminous, while the following side showed a rich, dark sky with the few small stars on it. From the view, one would not question for a moment that a real object—dusky looking, but very feebly brighter than the sky—occupies the place of the spot. It would appear, therefore, that the object may be not a vacancy among the stars, but a more or less opaque body.

The photographs with a portrait lens show this object black against a luminous sky. The explanation of this apparent anomaly is that the sky about it is filled with innumerable small stars, both visible and invisible, with perhaps some nebulosity. The effect of these upon the plate is to counterbalance the feeble light from the matter forming the hole, and thus to produce by contrast the appearance of a vacant spot; or in other words, if the object were placed on the ordinary dark sky away from the Milky Way, it would be seen and photographed as a luminous spot, sharply defined on one side and diffused on the other; or, similar to a sun-spot, it is black only by contrast with its brighter surroundings. Perhaps this can be made clearer when we remember that the scale of the portrait lens is relatively very small, and that the stars crowd together here so thickly that their images on the photograph almost coalesce into a complete bright sheet, or continuous background, on which the spot stands out strongly. This of course accentuates the definiteness of the hole and the contrast it makes with the sky. If a sufficiently long exposure were

made with a long-focus instrument like the 40-inch telescope, to show the faintest stars on the portrait lens plate, the hole would not be recognizable except from the want of stars at that point. This is essentially what happens, only it is more marked, in the visual observations of this object with the large telescope.

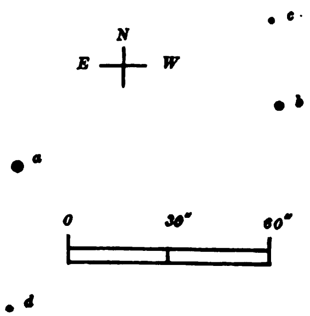


FIG. 1.—Chart of stars in black spot 1855.0: $\alpha=18^h7^m$; $\delta=-18°15'$.

At the suggestion of Professor J. C. Kapteyn, I have measured the position of the small star in the hole with respect to stars outside of it, as there is a possibility that the star is on this side of the general background. I have also measured the positions of several faint stars quite near with respect to it. See diagram, Fig 1.

THE CENTRAL STAR AND AN 8½ MAGNITUDE STAR FOLLOWING
(=*B.D.*−*18°4871* [$8^m.4$])

Date	$\Delta\alpha \cos\delta$	$\Delta\delta$
1913.504 July 3	$-301''.91$	$+0' 40''.3$
.513 6	-301.57	$+ 40.3$
.529 12	-301.65	$+ 40.3$
1913.515	-301.71	$+0 40.3$

$$\therefore \Delta\alpha = -0^m21^s.18.$$

On July 6, 1913, the $\Delta\alpha$ was also determined by transits:

$$\Delta\alpha = -0^m21^s.10 \text{ (8 tr.)}.$$

On this last date also, I measured by transits the position of the small star relative to a 9th-magnitude star preceding it, =*B.D.* −*18°4853* ($9^m.2$) = Bordeaux A.G.C. *5313*.

1913 July 6 $\Delta\alpha$ (small star -9^m star) $+1^m7^s.11$ (8 tr.)
$\Delta\delta$ $+2'26''.4$ (4).

These last measures give the position of the small star (which we shall call *a*):

$$1913.0 \qquad \alpha=18^h10^m28^s.82 \qquad \delta=-18°15'27''.3.$$

Singularly enough the star 4853 is in the *Bordeaux Catalogue* (No. 5313), while 4871, a much brighter star, is not.

Following are the measures of the smaller stars:

a and *b*

Date		P.A.	Dist.	Mags.
1911.391	May 23	285°.25	80.67	11.0 13.0
.424	June 4	282.41	80.34	12.2 13.9
.429	6	282.32	80.37	
.462	18	282.14	80.59	
1913.504	July 3	282.30	80.33	
1911.842		282.88	80.46	11.9 13.6

b and *c*

1911.391	May 23	3°.62	25″.76	15.5
.424	June 4	3.56	25.38	16
.462	18	5.73	25.01	15
1911.426		4.30	25.38	15.5

a and *d*

1913.570	July 27	176°.13	42″.14	15½
.576	29	175.83	42.43	16½
1913.573		175.98	42.28	16

On June 18, 1911, *d* was estimated to be of the 16th magnitude. It is very faint and difficult to measure, and is shown very feebly on the original photograph. The star *c* is difficult to measure unless the seeing is good.

The plate also shows a narrow black marking some 20′ following the one under discussion. This is very black in its north end, and is doubtless of a similar nature to the larger one.

Another black spot, which I came across some thirty-odd years ago,[1] is perhaps still more remarkable because it is even smaller (5′ ± in diameter). It is found in a dense part of the Milky Way, in about the position:

$$1875.0 \qquad \alpha = 17^h 55^m.1 \qquad \delta = -27°59'.$$

[1] *Astronomische Nachrichten*, 108, 369, 1884.

It is a very striking object in a 5-inch telescope, where it looks like a drop of ink on the luminous sky. The photographs show it black, but with some faint stars in it. On the preceding border is a bright orange-colored star (perhaps *Argentine General Catalogue*, 24531 [8½ mag.])

$$1875.0 \quad \alpha = 17^h 55^m 32^s.04 \quad \delta = -27°53'19''.8.$$

Near the hole, and preceding it, is a cluster of small stars.

There are many other small black spots in the Milky Way (which are shown on my photographs) in which I am interested, and of which it is hoped soon to make a catalogue. A considerable number of very small ones are found in the great star cloud whose center is in

$$1855.0 \quad \alpha = 18^h 46^m \quad \delta = -7\tfrac{1}{2}°.$$

With respect to the question of obscuration of light in space, there is one other object which strikingly shows this effect. In the east side of the well known nebulous stream that runs southward from ζ *Orionis* is a very conspicuous black notch which is very sharply defined. This striking feature is well shown on a photograph by Dr. Isaac Roberts which was printed in the *Astrophysical Journal*, **17**, Plate IV. In the text of his article ("Herschel's Nebulous Regions") at p. 74, Dr. Roberts refers to the dark spot as an "embayment," and dismisses it with the following statement: "To the south of ζ is a stream of nebulosity, 54′ of arc in length, with an embayment free from nebulosity dividing it in halves."

This object has not received the attention it deserves. It seems to be looked upon as a rift or hole in the nebulosity, as implied in the quotation from Dr. Roberts' paper. I have made numerous photographs of it, and in the past winter gave a long exposure with the expressed purpose of showing more definitely the true form of the object. This last photograph on February 7, 1913, with an exposure of $4^h 33^m$, shows the nebulosity better than I have seen it before. Instead of an indentation, the almost complete outline of a dark object is shown projected against the bright nebulosity. The west side of it is very definite and sharp, while the eastern limit is scarcely discernible, and is entirely lost in the enlargement. The best description I can give of it is to

present the photograph of the object itself for inspection (Plate XX, Fig. 1). A glance at the original would show that this is not a perforation in the nebula. It is clearly a dark body projected against, and breaking the continuity of, the brighter nebulosity. Possibly this is a portion of the nebula itself nearer to us, but dark and opaque, that cuts out the light from the rest of the nebula against which it is projected.

On the night of November 4, 1913, with good conditions of seeing and fair transparency, I examined this object with the 40-inch telescope and a power of 460. The position was carefully located with the aid of the photograph. The outlines of the spot—so sharp and clear in photographs of this region—could not be made out with any definiteness. The view showed that the spot is certainly not clear sky, for the field was dull, apparently indicating the presence of some material substance at this point. To me the observation would confirm the supposition of an obscuring medium at this point.

The position of this remarkable object from the *B.D.* charts is

$$1855.0 \qquad \alpha = 5^h 33^m\!.6 \qquad \delta = -2^\circ 35'.$$

YERKES OBSERVATORY
November 15, 1913

Minor Contributions and Notes

THE VARIABLE RADIAL VELOCITY OF *113 α PISCIUM*

The variable velocity of this double star ($\alpha = 1^h 57^m$; $\delta = +2° 17'$; mags. 5.2 and 4.3; type A2p) was established immediately after the second and third plates had been obtained. The possibility of misleading influence due to the spectrum of the fainter star led the director to suggest separating the two stars on the slit of the spectrograph. (The present distance of the components is about 2″.4, the angle 318°.) This was readily done on a night of average "seeing" by removing the correcting lens, which causes the blue images to coalesce, and by guiding with the stars in focus for visual light. This involves shortening the focal setting of the spectrograph by 34 mm and lengthening the exposure time to about 75^m for the brighter and about 100^m for the fainter star.

The first pair of plates of the separated images was obtained on October 9, 1908, after a long and a short exposure had been made in the usual way to see if the presence of the fainter spectrum could

TABLE I

Observations of the Blended Spectrum

Plate	Date	Julian Day	Taken by	Velocity	No. of Lines	Quality
				km		
IB 1274.......	1907 Dec. 6	2417916.551	F	− 5.0	11	v.g.
1695.......	1908 Aug. 24	8178.855	L	+15.6	11	g.
1703.......	Aug. 25	8179.780	L, B	+24.0	10	f.
1713.......	Aug. 28	8182.858	L	+ 2.0	9	g.
1721.......	Sept. 7	8192.828	L	+ 6.2	8	f.
1729.......	Sept. 8	8193.730	L	+19.0	9	v.g.
1730.......	Sept. 8	8193.765	L, B	+ 2.4	10	v.g.
1740.......	Sept. 18	8203.819	L	+12.9	9	f.
1757.......	Sept. 25	8210.793	B, L	+ 6.1	6	g.
1768.......	Oct. 2	8217.826	L	+ 4.1	9	v.g.
1775.......	Oct. 5	8220.780	L, B	+ 4.3	4	g.
1782.......	Oct. 9	8224.659	L	+ 8.5	13	v.g.
1783.......	Oct. 9	8224.682	L	+ 8.3	7	g.

In column 4, "Observer," B = Barrett; F = Frost; L = Lee. Mr. Sullivan, as usual, assisted in observing.

be detected in this manner. All later observations have been made upon the separated stars. Only three pairs of plates were obtained that season, and to our surprise, these failed to show any appreciable variation of velocity in either component. Additional plates secured during the past year prove that each star is binary. Meanwhile Campbell in *Lick Observatory Bulletin* **6**, 142, 1911, announced the variable velocity from observations of the blended light. Reference to No. 1061 in Burnham's *General Catalogue*, shows that the changes in orbital velocity of the two stars are inappreciable for the period covered by the spectrographic observations.

On Plates 1721 and 1729 violet components were measured which gave velocities of −6 and −12 km from 4 and 6 lines, respectively. The decrease in velocity from No. 1729 to No. 1730 may be caused by the line complexity in the former. The long and short exposure plates 1782 and 1783 show no differences in spectrum and the close agreement of the velocities derived indicates a superposition of the component lines in this particular phase.

TABLE II

Observations of the Brighter Star

Plate	Date	Julian Day	Taken by	Velocity	No. of Lines	Quality
				km		
IB 1784.......	1908 Oct. 9	2418224.722	L	+ 0.1	6	g.
				− 1.3	7	
1811.......	Oct. 30	8245.876	L	+ 2.3	6	g.
				+ 3.3	3	
1820.......	Nov. 2	8248.783	L, B	+ 6.3	5	g.
				+ 6.1	4	
3175.......	1912 Nov. 29	9736.625	L	− 0.3	7	v.g.
				− 3.0	9	
3217.......	Dec. 27	9764.674	L	+17.4	5	v.g.
				+17.2	5	
3256.......	1913 Jan. 24	9792.502	L	− 3.3	8	v.g.
				+ 0.3	5	
3266.......	Feb. 3	9802.515	L	+25.3	8	g.
				+28.7	5	

The second measure given for each plate is a duplicate made recently as a check, and the means may be taken without weighting. The region from H_γ to H_β was used. No real differences in the two spectra have been observed.

TABLE III

OBSERVATIONS OF THE FAINTER STAR

Plate	Date	Julian Day	Taken by	Velocity	No. of Lines	Quality
				km		
IB 1785.......	1908 Oct. 9	2418224.792	L	+4.0	7	g.
				+4.0	5	
1810.......	Oct. 30	8245.809	L	−1.8	6	g.
				+1.0	5	
1819.......	Nov. 2	8248.712	L	+5.8	5	g.
				+5.4	6	
3176.......	1912 Nov. 29	9736.699	L	+19.7	7	v.g.
				+22.9	5	
3216.......	Dec. 27	9764.603	L	+5.7	8	v.g.
				+3.9	3	
3257.......	1913 Jan. 24	9792.572	L	+20.4	6	v.g.
				+19.7	5	
3267.......	Feb. 3	9802.586	L	+4.1	7	g.
				−1.6	5	

The average exposure time for the brighter star is 75^m; for the fainter 104^m, or 39 per cent longer. Estimates of the relative strengths of exposure of the plates, taken pair by pair, show that the plates of the fainter star are on an average about 30 per cent stronger than those of the brighter star. That is to say, the two spectra are of about the same magnitude photographically while differing by 0.9 of a magnitude visually. This would hardly be expected, considering the practical identity of the spectra. The data for the separate stars are too meager to justify a statement about the period. The chance is more than even that higher dispersion will show components for either or both of these stars and two or three prisms should be used in further investigations of them.

OLIVER J. LEE

YERKES OBSERVATORY
October 1913

ON SLIPHER'S SPECTROGRAMS OF THE MAJOR PLANETS

In *Nature* (**79**, 42, 1908) Professor P. Lowell has published a table of spectra of the major planets, composed by V. M. Slipher on the basis of his spectrograms obtained at the Lowell Observatory.

Two botanists—Beijerinck and Timirjasev—showed almost

at the same time, that among the dark bands in the spectra of *Uranus* and *Neptune* there is one (between B and C), which coincides with the most characteristic band of the absorption spectrum of chlorophyl.

In *Bulletin No. 42* of the Lowell Observatory Slipher had published a longer article on the spectra of the major planets. He indicated here that between B and C at λ 6670 (mean) there is also "a very broad and very weak" band in the spectra of *Jupiter* and *Saturn* (p. 237).

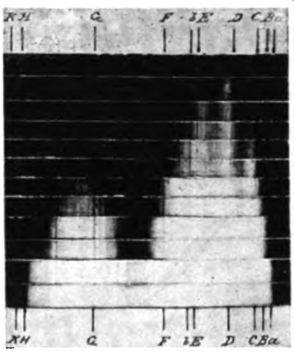


FIG. 1

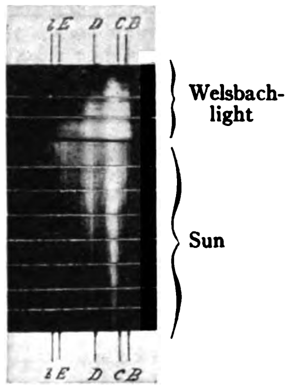


FIG. 2

Slipher's spectrograms were taken upon plates sensitized with dicyanin, pinacyanol, and pinaverdol. Yet photographic plates sensitized with dyes have not ordinarily a uniform sensitiveness in all parts of the spectrum; their "sensitiveness-spectrum" depends upon the absorption spectrum of the dyes employed.

I have investigated how far the sensitiveness of photographic plates is in fact uniform after sensitizing with pinacyanol, pinaverdol, dicyanin, homocol (also employed by Slipher), and their combinations. I have found that neither any single dye of those named, nor their combination, gives a plate of perfectly uniform sensitiveness.

The sensitiveness-spectrum of a plate, sensitized after Slipher's method (with washing in water), may be seen in Fig. 1. This figure is composed of a series of spectrograms of the sun taken with a gradually increasing exposure. On the lowest spectrogram,

taken with a very long exposure ("over-exposed"), all the bands of the sensitiveness-spectrum have disappeared.

In Fig. 2 we see the less refrangible half of the spectra only. This plate was sensitized like those mentioned above, but the dyes were "diluted with equal parts of water and alcohol," and "rinsed in alcohol" according to the other modification of Slipher's method. The three upper spectra are those of the Welsbach-light, the lower—taken at the same time—of the sun. *The dark band between* B *and* C *is here very strong.*

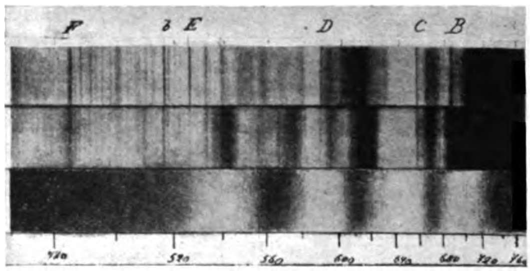


FIG. 3

It may be thought that I simply have not succeeded in obtaining plates of so uniform a sensitiveness as did Slipher. But on Slipher's own spectrograms of *Mars*, and especially of the moon, reproduced in "The Spectrum of *Mars*" (*Astrophysical Journal*, **28**, 1908, Plate XXXVI, Figs. 1 and 2), these minima of sensitiveness are quite clearly visible.

To show these dark bands strongly the dispersive power of the prism employed must be low and the exposure short. Both these conditions were present in the case of Slipher's spectrogram of *Uranus*.

The comparison of Slipher's spectrum of *Uranus* with my spectrograms of the sun and of the Welsbach-light (Fig. 3) makes it seem very probable that in Slipher's case we have a combination of the true spectrum of *Uranus* with the sensitiveness-spectrum of the sensitized plate.

The actual existence in the spectrum of *Uranus* of the band between B and C is therefore subject to doubt until it is confirmed by other methods.

Consequently there is at present no solid ground for the comparison of the spectrum of *Uranus* with the spectrum of chlorophyl, the presence of which in the major planets is very improbable.

V. ARCICHOVSKIJ

NOVOČERKASSK
June 2, 1913

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AUTHORS